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WHIPTAIL — Moly-deficiency disease common in such crops as broccoli, brussels sprouts, turnips. Shown here in cauliflower. Young leaves are long and narrow, irregularly shaped. Leaf tissue does not develop normally from midrib. Midrib left bare in places.



INTERVEINAL MOTTLING—As example, moly-deficient tobacco shown here. Leaves in young plants turn pale yellow between veins and sometimes around margin. Veins remain green giving leaf mottled appearance. Pale areas develop into clearly defined yellow spots.



PALE CUPPED LEAVES — Overall pale coloration appears in many moly-deficient plants, like tomato on left. Leaves often curl or cup upward around edges.



STUNTED GROWTH — In sugar beet plants compared here, deficient plant on left made almost no growth of roots or tops. Small moly deficiencies retard crop yield.

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Winter Hardiness of Birdsfoot Trefoil Strains and Varieties¹

Kenneth O. Rachie and Alois R. Schmid²

THE use of birdsfoot trefoil (*Lotus corniculatus* L.) as a permanent pasture legume is dependent in part on its ability to survive winter injury. In Minnesota and other northern areas where birdsfoot trefoil might be grown, there appears to be some doubt as to the winter hardiness and persistence of this legume. For this reason, studies were made on the relative winter hardiness of birdsfoot trefoil strains and varieties.

Winterkilling may be the result of several factors. Levitt (7) has reviewed much of the work done on the physiology of winter hardiness. Among the factors for winterkilling most often listed and studied are varieties, food reserves, heaving, ice sheet injury, diseases and chemical makeup of the plant as influenced by soil fertility. Important studies of these factors, particularly as related to legumes, have been reported by many workers (1, 2, 3, 4, 5, 6, 10, 11, 14, 15, 16, 17, 18). The stage of development of plants and their resistance to cold injury was studied by Tysdal and Pieters (16) and Peltier and Tysdal (12). Several workers have observed differentials in winter killing among varieties and strains within a species. Aamodt, *et al.* (1) noted differences among strains of white clover. Brink, *et al.* (2) studied alfalfa strains and found significant differences among them. Since disease is an important factor, it is of interest to note that MacDonald (9) reports that clover root rot, *Sclerotinia trifoliorum*, has been observed to infect birdsfoot trefoil and cause a reduction of stand. Lewis and Sherwin (8) observed that *Rhizoctonia solani* also attacks birdsfoot trefoil.

The investigations presented here include artificial hardening and freezing of different varieties grown in the greenhouse, and observations made on winter killing of varieties grown in the field. These artificial treatments were used to compare tissue hardiness of different varieties and to supplement studies made in the field since winter killing varies considerably from year to year.

MATERIALS AND METHODS

Greenhouse Experiment

Plants were grown in the greenhouse to different stages of development, artificially hardened, and frozen in a walk-in type freezer. Ranger alfalfa and Ladino clover were used for comparison with birdsfoot trefoil in this experiment. Ranger alfalfa is sufficiently winter-hardy in Minnesota to survive most winter conditions encountered. Ladino clover, on the other hand, is more susceptible to winterkilling.

Five different freezings were made on Ranger alfalfa, Ladino clover, and five varieties of birdsfoot trefoil namely, Viking, Empire, Cascade, Granger, and Italian. Seedlings were made in

6-inch clay pots, and enough seed was used to give at least 30 seedlings per pot for the earlier treatments and at least 20 seedlings per pot for the later treatments.

A greenhouse potting soil consisting of an equal mixture of soil, sand, and manure was used. All the pots and soil were steam sterilized before planting. The seed was treated by dusting with Spergon. The seeds were carefully scattered in the pot and kept at least 1/2 inch away from the sides of the pot to avoid unequal freezing injury near the outside. The seed was covered with 1/8 inch of lightly packed soil. A generous sprinkling of the appropriate Rhizobia was then made on top of the soil to be washed down to the seedlings with later waterings. The pots were regularly watered to insure optimum growth. The greenhouse temperature was kept at about 22° C. except on sunny days when the temperature was higher. Artificial light was not used since the experiments were started late in March when natural light was ample.

After 2 weeks of growth, the seedlings in each pot were thinned to approximately 20 to 30 plants per pot. Hardening of the plants and freezings as described later were made after 14, 19, 24, 36, and 44 days of growth. Each variety was duplicated in each treatment and the pots were randomly arranged in two blocks. Seedlings for all treatments were made on the same day and the hardening and freezing treatments were made after the prescribed number of days of growth in the greenhouse.

When the prescribed number of days of growth for each treatment had elapsed, the seedlings were transferred to the hardening chamber for 14 days. In the hardening chamber the temperature was maintained at 3° C. Fluorescent lights about 18 inches above the seedlings were continuously used. Water was supplied when needed. Very little or no growth was observed in the hardening chamber.

After hardening, the pots were transferred to the freezing chamber for 12 hours at -10° C. Before freezing, notes were taken on height of plant, number of trifoliate leaves and the number of plants per pot. After freezing, the pots were returned to their original position in the greenhouse and the number of surviving plants was recorded 10 days later.

Field Experiments

Two separate studies were made of the survival of birdsfoot trefoil varieties in the field. One study was conducted at Rosemount where five varieties of trefoil and Ranger alfalfa were seeded on June 20, 1951. Each plot consisted of 10 rows, 6 inches apart, and replicated 6 times. Four-hundred pounds per acre of 0-20-10 fertilizer were applied before seeding. The birdsfoot trefoil varieties and Ranger alfalfa were seeded with a 1-row garden planter at a rate of 5 and 12 pounds per acre, respectively.

On May 6, 1952, the percent survival of each variety was calculated from the plants remaining alive. Plants 5 feet in from each of 2 center rows of each plot were counted.

The second study of variety survival was carried on at the University Farm in St. Paul. In this experiment six varieties of birdsfoot trefoil plus Ranger alfalfa were included. These varieties were Oregon Narrowleaf, French Broadleaf, Italian Broadleaf, Granger, Empire, and Cascade. These plots were seeded on July 22, 1952 and consisted of 12 rows, 6 inches apart and 20 feet long. Plots were again replicated 6 times and the seeding was also done with the garden seeder calibrated for 10 pounds per acre of alfalfa and 5 pounds per acre of trefoil. All seeds were inoculated with their appropriate nitrogen-fixing bacteria. The percent survival of the varieties was calculated from counts made on the same area on Sept. 19, 1952 and again on April 23, 1953. Counts were made on 12 feet of a row. Notes were also taken on height of plants and their over-all vigor. In the spring of 1954 a note on percent survival was obtained by eye estimation.

¹ Contribution from the Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 3210, Scientific Journal Series, Minnesota Agr. Exp. Sta. Part of a thesis submitted to the Graduate School by the senior author in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Rec. for publication Aug. 26, 1954.

² Former graduate student and Associate Professor of Agronomy, respectively.

Table 1.—Survival after artificial freezing of Ranger alfalfa, ladino clover and birdsfoot trefoil varieties after 14 to 44 days of growth in the greenhouse.

Variety	14 days		19 days		24 days		36 days		44 days		Average percent survival
	Stage	Percent survival	Stage	Percent survival	Stage	Percent survival	Stage	Percent survival	Stage	Percent survival	
Ranger alfalfa	2-3 in. 1-leaf	0.0	2-3 in. 3-leaf	91.3	5-6 in. 5-leaf	100.0	8-9 in. 9-leaf	100.0	9-11 in. 12-leaf	100.0	97.8
Ladino clover	2-3 in. 1-leaf	0.0	2-3 in. 1-leaf	47.2	3 in. 2-leaf	79.3	3-4 in. 4-leaf	50.7	7-8 in. 5-leaf	16.0	48.3
Viking trefoil	2-3 in. 3-leaf	0.0	3-4 in. 5-leaf	88.1	4-5 in. 6-leaf	88.6	6-7 in. 9-leaf	72.1	8-9 in. 10-leaf	95.0	86.0
Empire trefoil	2-3 in. 2-leaf	0.0	2-3 in. 4-leaf	81.6	4-6 in. 6-leaf	83.9	7-9 in. 8-leaf	85.0	9-10 in. 11-leaf	100.0	87.6
Cascade trefoil	2-3 in. 3-leaf	0.0	3-4 in. 5-leaf	56.9	4-5 in. 7-leaf	79.1	6-7 in. 9-leaf	91.2	7-8 in. 11-leaf	97.6	81.2
Granger trefoil	2-3 in. 3-leaf	0.0	3 in. 5-leaf	50.0	5-6 in. 7-leaf	71.8	6-7 in. 10-leaf	70.6	8-9 in. 12-leaf	68.3	63.9
Italian trefoil	2-3 in. 3-leaf	0.0	3-4 in. 5-leaf	35.4	5-6 in. 7-leaf	56.3	6-7 in. 9-leaf	55.5	7-8 in. 10-leaf	82.3	57.4
Average		0.0		64.4		79.9		75.0		79.9	74.8
L.S.D. between varieties at 5%											21.4

EXPERIMENTAL RESULTS

Greenhouse Experiment

Data obtained from the artificial freezing study are shown in table 1. When the plants were allowed to grow only 14 days in the greenhouse before hardening and freezing, no plants survived. Therefore, results from this stage were omitted from the analysis of variance. According to the analysis, the F values for varieties and for varieties $\times$ treatments were significant at the 1% level.

Ranger alfalfa had significantly greater hardiness than Ladino clover, Granger and Italian trefoil. In this experiment Ranger alfalfa did not have a significantly higher survival rate than Viking, Empire, and Cascade trefoils. Nevertheless, it was consistently superior for each growth period (19, 24, 36 and 44 days of growth before hardening and freezing) and had more recovery vigor, suggesting that it is superior to these three varieties in hardiness.

Viking, Empire and Cascade birdsfoot trefoils are more resistant to freezing injury than Italian birdsfoot trefoil and Ladino clover. Viking and Empire may be hardier than Granger. No other varietal differences are significant. Ranger alfalfa, Viking and Empire trefoils, under the conditions of this experiment, seemed to approach maximum survival rate with 19 days of growth before hardening and freezing. Ladino clover and Cascade, Granger and Italian trefoils, appeared to continue to increase in hardiness up to 24 days of growth. The survival of Ladino clover decreased sharply from the 24-day growth period to the 44-day growth period and was less hardy at the 44-day growth period than at the 19-day growth period.

Field Experiment At Rosemount

Five varieties of birdsfoot trefoil and Ranger alfalfa were seeded on June 20, 1951 at Rosemount. Observations made the following spring on survival of these varieties are recorded in table 2.

The most striking result is that four varieties of birdsfoot trefoil, Granger, Italian, French, and Oregon Narrowleaf were completely winterkilled and that Ranger alfalfa and Empire birdsfoot trefoil survived relatively well.

Ranger alfalfa was found to have significantly more winter hardiness than Empire trefoil in this comparison.

Field Experiment at University Farm, St. Paul

Another variety seeding was made at the University Farm in St. Paul on July 22, 1952 to test further the relative hardiness of birdsfoot trefoil varieties. Seven varieties of trefoil and Ranger alfalfa were used in this trial. The data on percent survival after each of the two following winters are presented in table 3.

In the 1952-53 winter, Ranger alfalfa and Empire trefoil had significantly better survival than Oregon Narrowleaf, Italian and French. Ranger and Empire, although not significantly different from Cascade and Granger, tend to be consistently higher in survival. During the 1953-54 winter the varieties French, Italian, Oregon Narrowleaf, Granger and Cascade were almost eliminated by winter injury. Only Ranger alfalfa and Empire birdsfoot trefoil showed good survival.

Table 2.—Survival of birdsfoot trefoil varieties and Ranger alfalfa in field trials at Rosemount, Minn., after the winter of 1951-1952.

Variety	Percent survival
Granger	0
Italian	0
French	0
Oregon Narrowleaf	0
Empire	86.0
Ranger alfalfa	97.8**

** Difference between Empire and Ranger alfalfa significant at 1% level.

Table 3.—Survival of birdsfoot trefoil varieties and Ranger alfalfa after the winters of 1952–1953 and 1953–1954.

Varieties	Percent survival	
	1952–1953	1953–1954
French	87.6	4.0
Italian	55.6	4.0
Oregon Narrowleaf	74.1	2.0
Granger	92.1	3.0
Empire	99.1	89.0
Cascade	93.2	2.0
Ranger alfalfa	99.3	93.0

L.S.D. between varieties at 5% = 7.3 for the 1953 winter.

DISCUSSION

Ranger alfalfa generally had more winter hardiness than any of the trefoil varieties tested in all studies made. However, in some cases in both the field and greenhouse, no significant differences could be found between Ranger alfalfa and Empire, Viking, Cascade, or Granger birdsfoot trefoil. The reason might have been due to a freezing temperature that was not low enough to get a good differential in the greenhouse experiments. At University Farm in St. Paul, the winter of 1952–53 was not rigorous enough to severely injure even the least hardy varieties. During the 1953–54 winter the varieties French, Italian, Oregon Narrowleaf, Granger and Cascade were severely winter injured. At Rosemount the 1951–52 winter was severe, and the trefoil varieties—Granger, Italian, French, and Oregon Narrowleaf—were completely killed while Ranger alfalfa, and Empire birdsfoot trefoil showed good survival.

Empire birdsfoot trefoil in the field and greenhouse is somewhat more cold resistant than other varieties of trefoils tested. In the greenhouse, however, Viking was not observed to be significantly less hardy than Empire. Further study of the winter hardiness of Viking in the field and by artificial freezing seems warranted since this variety had good vigor, resistance to disease, and recovery from freezing. Seed of this variety was not available in time to be included in these field studies. Although Empire has good cold hardiness, it has a slower recovery and seems to have less vigor than other varieties of trefoil. This is in agreement with Ronningen's (13) work on white clover when he obtained a significant negative correlation between vigor and winter hardiness.

The results obtained with Ladino in the greenhouse were quite variable. This may have been due to Ladino having a rather narrow range of freezing resistance or because resistance to freezing fluctuates with growth.

Freezing at different stages of growth was studied to determine how soon seedlings obtain sufficient cold hardiness. The first artificial freezings were made when all seedlings had made a minimum of 14 days of growth, and all varieties were killed at this stage. Ranger alfalfa, Viking and Empire trefoil, had very good resistance to freezing after 19 days of growth, each averaging better than 80% survival. Ladino, Granger, Cascade, and Italian seem to require more than 19 days of growth before obtaining relatively good resistance to freezing. Peltier and Tysdal (12) concluded that 10 to 18-day old alfalfa seedlings are relatively susceptible to freezing in comparison to both younger and older seedlings. Tysdal and Pieters (16) also showed that alfalfa and red clover increase in cold resistance with advance in age after the two-leaf (trifoliate leaves) stage.

The results presented here agree with those of Peltier and Tysdal and Tysdal and Pieters. Certain varieties of trefoil however, probably require longer growth than others before they can tolerate freezing temperatures.

SUMMARY

Winter hardiness experiments using field conditions and artificial freezing showed that Empire birdsfoot trefoil was more winter-hardy than the other trefoil varieties tested, with the possible exception of Viking, which was tested only by artificial freezing.

There were no varieties which survived freezing after only 14 days of greenhouse growth, but all varieties had at least fair survival after 19 days of greenhouse growth. Ranger alfalfa, Empire, and Viking birdsfoot trefoil had good survival after 19 days of greenhouse growth, whereas Ladino clover, Granger, Cascade and Italian birdsfoot trefoil were less hardy at this stage of growth.

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Evaluation of Combining Ability in Orchardgrass *Dactylis glomerata* L.¹

Donald L. Oldemeyer and A. A. Hanson²

RECOGNITION of the importance of grassland farming and the need for improved forage production has emphasized the demand for superior forage varieties. Selecting parents which transmit desirable characters to their progenies is the main problem that confronts the plant breeder in developing such varieties.

Combining ability has been recognized in selecting desirable inbred lines of corn. The success of this type of selection is well illustrated by the improved performance of hybrid corn varieties. On the other hand, neither the methods nor the importance of selecting on the basis of combining ability have been adequately investigated for perennial forage grasses.

This investigation was undertaken to compare three different means of evaluating combining ability in orchardgrass. The methods differed by the range of pollen available to the parents for fertilization. The pollen sources were varied by including selected clones in wide and restricted polycross nurseries and in single-cross blocks.

REVIEW OF LITERATURE

Tysdal and Crandall (7) demonstrated the need for selecting parents of high combining ability to produce high yielding alfalfa synthetics. They produced two synthetics, one with high combining parents and one with low combining parents. The former yielded 29% more forage in the first generation than did the low combining synthetic. They concluded that as long as there is considerable genetic variability among the lines in the polycross nursery, the polycross test should measure general combining ability efficiently. Eight alfalfa clones evaluated through progenies from single-crosses, a polycross nursery, a polycross nursery with Arizona Common in alternate rows, and top-crosses with Arizona Common, ranked practically the same in each test.

Knowles (4) studied combining ability in smooth bromegrass and crested wheatgrass. Combining ability ratings from open-pollinated progenies agreed with the ratings from controlled crosses among clones of crested wheatgrass. A reasonably good agreement was noted between the yields of variety top-cross and open-pollinated progenies. The polycross and open-pollinated progenies of bromegrass gave similar yields; however, a non-significant correlation was obtained between the yields of open-pollinated and single-cross progenies. The lack of agreement was attributed to the presence of selfing in the single-crosses. In general, Knowles found a poor relationship between parental performance and progeny performance. He suggested the use of open-pollinated progenies to evaluate selections for yield potential. He agreed with Sprague and Tatum (6) that general combining ability is more important than specific ability in lines not previously tested and selected for combining ability.

Weiss, *et al.* (9) found very little association between orchardgrass clones and their open-pollinated progenies for forage yield or leafiness. Poor association was also noted between the yields of single-crosses and the mean yields of the parents. The test

was planted in 3-foot drill rows. They stated that the use of broadcast plots probably would have given a more accurate evaluation of progenies. They mention that the open-pollinated seed was obtained from single plants in a space-planted nursery. Thus, male parentage was confounded in their experiment.

Murphy (5) compared the performance of parental clones with that of polycross and selfed progenies from three species of grasses. Drilled, broadcast, and spaced plantings were used. Significant positive correlations were obtained between parental and progeny yields regardless of method of planting. According to these investigations, any of the methods tested could be used in selecting for high yield potential.

Hanson, *et al.* (2) compared the general combining ability of 18 parental clones of orchardgrass and 52 of their inbred lines in broadcast plots. The results indicated that there was little relationship between combining ability and level of inbreeding. They suggest that lines within families should be evaluated for combining ability.

Wilsie and Skory (10) found a possible association between forage yields of single-cross and open-pollinated progenies of alfalfa clones that might be of assistance in evaluating combining ability. They stressed the need of determining specific combining ability in the selection of lines to be included in synthetics.

Bolton (1) and Knowles (4) compared reciprocal crosses and found very little difference in their behavior. Knowles did find some instances in bromegrass where significant differences occurred. Self-fertilization during crossing was suspected to have caused the differences.

Hawk and Wilsie (3) found greater variation in forage yield of parental clones than for open-pollinated progenies in bromegrass. Of 78 clones evaluated, only a few produced open-pollinated progenies superior in yield. Yielding ability of the parents and the open-pollinated progenies showed some relationship. They attributed 20 to 35% of the variability in progeny yields to differences in the yield potential of the parents. They advocate careful screening of parental material before progeny testing and the use of replicated single hill nurseries for clonal evaluation. They obtained data that would indicate seedling vigor tests may be of value for screening large numbers of open-pollinated progenies.

In testing six ways of planting, Weiss and Mukerji (8) found that broadcasting orchardgrass alone gave more accurate evaluation of strains than 1-foot or 3-foot drill rows. Broadcasting with alfalfa and birdsfoot trefoil were used as standards of the true potential of the lines.

MATERIALS

The parental clones trace back to a source nursery of 4,000 spaced plants. Of the original plants, 257 were selected and planted in a polycross nursery. Seed from 102 of these was planted and 38 selections were made on the basis of observational notes taken in the progeny test and in the clonal nursery. These were grouped according to maturity and planted into seven restricted polycross nurseries. The parents included in two of these nurseries were used in this study. Seven of the clones used were in an early group with May 31 as the average date of heading. June 11 was the average for the five clones in the late maturing group.

All of the seed used in the field experiments was harvested in 1949. Seed from the parental clones was collected at all locations in a wide polycross nursery having a total of 112 clones in 6 replications of 5 plants each. Progenies from this source will be referred to throughout the report by the abbreviation WPC.

Seed was harvested from each parent in their respective restricted polycross nurseries. The parents were planted in 10-plant rows and replicated 15 times in these nurseries. Progenies from this source will be designated by the abbreviation RPC. In addition to the bulked seed of individual parents, an early and a late synthetic were made by compositing equal quantities of RPC seed from parental clones of each group.

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Single-cross seed was obtained by interplanting the parents in all possible combinations within the early and late groups. Isolation was attained by dispersing the crossing blocks in wheat fields. The blocks consisted of 2 alternate 20-plant rows of each parent. Seed from each parent was harvested and threshed separately. To supplement this seed, panicles from adjacent plants were bagged in the restricted polycross nurseries. Since the supply of single-cross seed was insufficient for planting reciprocal crosses, each parent was represented by an equal weight of seed in the single-cross lots.

EXPERIMENTAL PROCEDURE

To obtain fertility indexes for the parents, panicles were bagged in 1950 and 1951. A total of 60 panicles per parent was used to determine the seed set under bags and an additional 60 panicles were used to determine open-pollinated seed set. Two parchment bags enclosing 3 panicles were placed on 10 plants of each parent for selfing and likewise for containing the open-pollinated panicles after fertilization. Self-fertility is expressed as a percentage of open-pollinated seed set.

The progenies were tested in two field experiments corresponding to the two maturity groups. The 7 early maturing parents and their progenies were planted in a randomized block design with 4 replications of 4- by 16-foot plots. Progenies of the five late maturing clones were planted as a split plot design of four replications with each entry being represented by a broadcast and a space-planted plot. The spaced individuals were established in 12-plant plots with a spacing of 2 feet within rows and 3 feet between rows.

The parents were included in both experiments as tiller plots. Tillers were established in flats after being rooted in water and transplanted on 6-inch centers in the field to simulate broadcast plots. The plot size, 4 by 8 feet, was only half that of the seeded plots.

Forage yields were obtained in 1951 and 1952. Both years were droughty so only two harvests were taken each year. First harvests were cut at full bloom and the second were cut when the grass was 6 to 8 inches tall. The spaced plants were harvested individually in 1951 and by plots in 1952. Yields are reported as oven-dry hay containing approximately 5% moisture.

In addition to the field experiments, 2 seedling trials were conducted in the greenhouse in the fall of 1951 to correspond to the 2 field experiments. They were designed to compare seedling vigor with field performance. The early maturing group was planted in a 6 by 7 triple rectangular lattice and the late group was arranged in a 5 by 5 triple lattice, both with 6 replications. The plots were arranged so that each flat contained one block with a border. A plot consisted of 2 rows of 6 plants. The eight inside plants of each plot were harvested.

The seedlings were harvested 53 days after planting. Plants from each plot were bulked, after cutting the tops from the roots, for drying. Root and top weights were recorded separately.

Correlation coefficients calculated for the agronomic characters were obtained by combining the data of the early group and the late group planted in broadcast plots. This gave 10 degrees of freedom for the r values to show parent-progeny relationships. The data from the two experiments were adjusted to their respective means in computing the sums of squares and sums of products.

EXPERIMENTAL RESULTS

FERTILITY INDEXES

According to the fertility indexes (table 1), all parents were highly self-sterile with the exception of parents MI-13 and MII-34 in the early maturity group and MIV-6 in the late group. The average fertility indexes for these 3 clones were 80, 22, and 35, respectively. No significant relationship was noted between selfed-seed set and open-pollinated seed set, the correlation coefficient being 0.26.

FORAGE YIELDS

Average yields of the parents and progenies for 1951 and 1952 are shown in figures 1 and 2. The single-cross yields are the average of all crosses involving the respective parents.

Table 1.—Average seed set per panicle for 2 years and the fertility indexes* of all parents given in percentage of selfed seed set to open-pollinated seed set.

Parents and Group	Seed set per panicle		Fertility Index
	Open-pollinated	Selfed	
Early Maturity			
MI-13	114.5	92.0	80
MI-14	69.5	2.5	4
MI-16	233.5	4.5	2
MI-17	155.0	1.5	1
MII-30	383.0	2.0	1
MII-34	94.5	20.5	22
MII-36	236.0	9.0	4
Late Maturity			
MIV-5	548.0	23.0	4
MIV-6	515.5	178.0	35
MIV-11	529.0	10.0	2
MIV-14	328.5	9.5	3
MIV-16	292.5	17.0	6

Significant differences in yields among entries were found in both experiments. The parents were predominately higher in yield than the progenies, mainly because the tiller plots became established faster and maintained this advantage possibly as a consequence of lower plant population. In both experiments, there was a significant interaction (0.01) of years $\times$ strains; however, significant correlations were found between the yields taken in 1951 and those in 1952. The interannual correlations for yields of parents, single-crosses, restricted polycrosses, and wide polycrosses were 0.58, 0.93, 0.87, and 0.94, respectively.

Considering the parent-progeny relationships, good associations were found as indicated by the correlation coefficients in table 2. All of the parent-progeny correlations were significant at the 0.05 level using the 2-year average yields. With the annual yields, some of the correlations only approached significance. The closest relationships existed between the parents and progenies of the late group planted in broadcast plots (figure 2).

Results of the space-planted portion of the late group experiment were somewhat different from those of the broadcast portion. There was a significant interaction of strains with methods of planting. MIV-14 appeared as one of the high yielding parents with high yielding polycross progenies contrary to the findings in the broadcast portion of the experiment.

Relationships among the progenies for yield were of about the same degree as between parents and progenies. In both instances, however, the correlation coefficients with the RPC's tended to be lower.

Mean yields of the single-crosses among the early parents are given in table 3. Specific combining ability was shown by all of the parents except MI-13 and MII-30. Each one had a single-cross that deviated significantly from the average of all the respective single-crosses. In all instances except MII-34 $\times$ MI-17, these crosses showed increases over the averages. Of the crosses with MI-13 and MII-30, all but one with each parent yielded above the average of all the single-crosses of the other parent in the crosses.

Single-crosses of the late maturing parents planted in broadcast plots (table 4) yielded as might be expected from the results of the polycross progeny tests and the parental

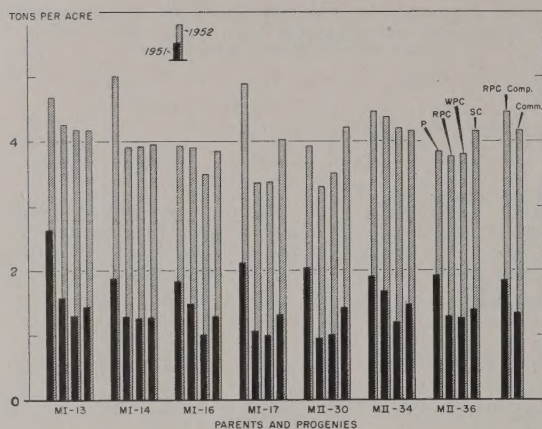


FIG. 1.—Average forage yields from the early maturity group for parents and progenies for two years. The single-cross yields are averages of all single-crosses for the respective parents.

Table 2.—Correlations among characters of parents and various types of progenies in broadcast plots.

Character	Year	Single crosses	Re-stricted poly-crosses	Wide poly-crosses
Yield:				
Parents	1951	0.66*	0.52	0.63*
Parents	1952	0.54	0.57	0.66*
	2-year ave.	0.63*	0.60*	0.74**
Single-crosses	1951	—	0.51	0.80**
Single-crosses	1952	—	0.58*	0.75**
	2-year ave.	—	0.54	0.80**
RPC's	1951	—	—	0.64*
RPC's	1952	—	—	0.76**
	2-year ave.	—	—	0.74**
Height:	1951			
Parents	—	0.89**	0.74**	0.76**
Single-crosses	—	—	0.74**	0.84**
RPC's	—	—	—	0.58*
Leaf rust:	1951			
Parents	—	0.90**	0.70**	0.78**
Single-crosses	—	—	0.72**	0.71**
RPC's	—	—	—	0.84**
Leaf spot:	1951			
Parents	—	0.89**	0.56	0.90**
Single-crosses	—	—	0.43	0.84**
RPC's	—	—	—	0.50

† Parent clones grown in tiller plots.

* $r=0.58$ for significance at 0.05 level.

** $r=0.71$ for significance at 0.01 level.

yields. Crosses among the three superior parents were all among the higher yielding single-crosses. MIV-14 and MIV-16 made low yielding crosses with MIV-6 and high yielding crosses with MIV-11 showing the expression of specific combining ability (table 4). This was in the broadcast plots only. There were no significant differences in yield among the single-crosses grown in spaced plantings.

HEIGHT

The association between parents and progenies and among progenies tended to be closer for height than for yield. All

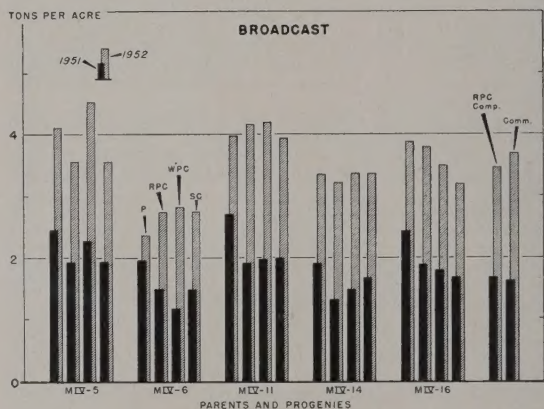
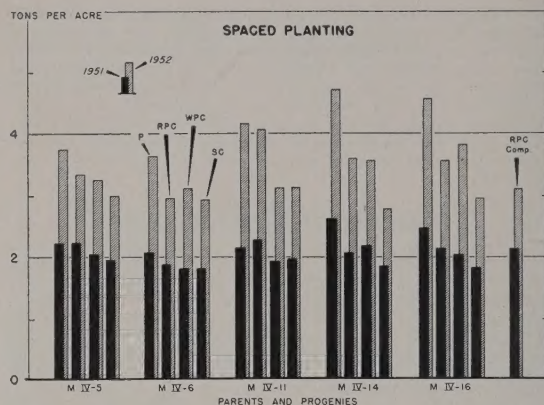


FIG. 2.—Average forage yields from the late maturity group for the parents and progenies. Yields are given for two years and for two methods of planting. The single-cross yields are the averages of all single-crosses for the respective parents.

of the correlation coefficients for height (table 2) were significant (0.05). As with yield, the correlations with the RPC's tended to be lower than the others. There was a correlation between yield and height in 1951. The r values for the early group, late group in broadcast plots and as space planted plots were 0.55, 0.86, and 0.64 respectively. All three were significant (0.01).

DISEASE

Disease ratings were recorded for all plots in 1951. Leaf rust, *Uromyces dactylidis* Oth., and Stagonospora leaf spot, *Stagonospora maculata* (Grove) Sprague, infections were rated on a 1 to 10 scale. Significant differences among entries were found for both diseases. The readings from the broadcast plots showed comparable relationships between parents and progenies and among progenies. The correlation coefficients (table 2) were significant or approaching significance except for single-cross vs. RPC for leaf spot. The r values for leaf spot involving RPC progenies were considerably lower than those relating the other progenies and parents.

Table 3.—Mean forage yields for 2 years of all possible single-crosses among the early maturing parents. Yields are given in tons per acre.

Parents	Parents							Averages
	MI-13	MI-14	MI-16	MI-17	MII-30	MII-34	MII-36	
MI-13	—	2.89*	2.59	2.68	2.92	3.04	2.71	2.80†
MI-14	2.89	—	2.22	2.36	2.65	3.21	2.35	2.61
MI-16	2.59	2.22	—	2.31	3.18	2.91	2.27	2.58
MI-17	2.68	2.36	2.31	—	2.98	2.31	3.40	2.67
MII-30	2.92	2.65	3.18	2.98	—	2.36	2.84	2.82
MII-34	3.04	3.21	2.91	2.31	2.36	—	3.06	2.82
MII-36	2.71	2.35	2.27	3.40	2.84	3.06	—	2.77

* Differences required for significance among crosses are 0.51 (0.05) and 0.68 (0.01).

† Differences required for significance among averages are 0.20 (0.05) and 0.28 (0.01).

SEEDLING VIGOR

Seedling vigor was measured by the production of oven-dry material, height and amount of tillering after 53 days of growth. Table 5 gives the correlation coefficients among the seedling characters and between seedling characters and field performance of the progenies tested. Significant correlations were found for the oven-dry weights of the above ground parts vs. height of the seedlings and tillering in both the early and late maturing groups. Correlations of seedling characters with field performance were not consistent. Seedling vigor as measured by top growth was significantly correlated with yields in the field for the late group tested in broadcast plots but not for the early group or the late group tested as spaced plants.

DISCUSSION

Although some of the parents were found to be highly self-fertile, there was no indication that progeny yields were adversely affected by the self-fertility. In the late maturity group where all progenies were represented as spaced plants, the number of weak plants in the progenies was not consistent with the self-fertility indexes of the parents. Parent MI-13 of the early group that had the highest self-fertility index, 80, would have been expected to produce the most offspring showing reduced vigor due to selfing but its progenies gave the highest yields. Either little selfing occurred under open-pollination or the reduction in vigor due to selfing was compensated for by the more vigorous plants in broadcast plots. In these tests it appeared the selfing potential of the parents was not a factor in progeny performance.

In evaluating the general combining ability of the parents, little difference was found between the effectiveness of the wide polycross and the restricted polycross progeny tests. Because the progenies from the two sizes of polycross nur-

Table 4.—Mean forage yields for two years of all possible single-crosses among the late maturing parents as broadcast plots and space-planted plots. Yields are given in tons per acre.

Parents	Parents					
	MIV-5	MIV-6	MIV-11	MIV-14	MIV-16	Average
MIV-5	—	2.45*	3.09†	2.70	2.75	2.75†
	—	2.68	2.68	2.32	2.21	2.47
MIV-6	2.45	—	2.47	1.82	1.74	2.12
	2.68	—	2.45	2.08	2.36	2.39
MIV-11	3.09	2.47	—	3.30	2.99	2.96
	2.68	2.45	—	2.49	2.63	2.56
MIV-14	2.70	1.82	3.30	—	2.23	2.51
	2.32	2.08	2.49	—	2.37	2.32
MIV-16	2.75	1.74	2.99	2.23	—	2.43
	2.21	2.36	2.63	2.37	—	2.39

* Top numbers are yields for the crosses in broadcast plots, bottom numbers are yields as spaced plants.

† Differences required for significance among crosses are 0.44 (0.05) and 0.59 (0.01) for broadcast plots.

‡ Differences required for significance among the averages are 0.22 (0.05) and 0.30 (0.01) for broadcast plots.

eries gave comparable evaluations of the parents for combining ability, it seems that the range of pollen available for fertilization is not critical with uniform pollen sources. Having fewer than five entries in a polycross nursery or having the pollen sources confounded, as in a source nursery, might cause varying results.

The average yields of the single-cross progenies from the respective parents were significantly correlated with parental and polycross yields; however, there was considerable

Table 5.—Correlation coefficients for the relationship among seedling characters and between seedling vigor and field results.

Characters Correlated	Early Group		Late Group			
	Broadcast		Broadcast		Spaced	
	r	n	r	n	r	n
Top weight of seedlings vs. height of seedlings	0.34*	36	0.91**	22	—	—
Top weight of seedlings vs. tillering of seedlings	.49**	36	.59**	22	—	—
Top weight of seedlings vs. two year average yield in field	-0.18	35	.55**	21	0.08	21
Height of seedling vs. height of second cut in field	-.08	35	.66**	21	—	—

Significant at 0.05 level.

** Significant at 0.01 level.

variation among the crosses of individual parents. The exhibition of specific combining ability among both groups of parents studied illustrates the importance of considering specific combining ability where only a few parents are to be combined into a synthetic variety. Although the major part of selection can be made from parental and polycross progeny performance, single-cross testing appears to be desirable for final evaluation.

Since the 2 years that the plots were harvested were droughty, the first cutting produced the greater portion of the yield particularly since they were cut at the hay stage. Perhaps cutting earlier to simulate pasturing or removal for ensilage would have lowered the correlations between height and yield. The high heritability of height may have contributed considerably to the relatively high parent-progeny r values.

It was noticed in comparing the various parent-progeny relationships that the correlation coefficients with the RPC's tended to be lower than the others. No explanation is offered for this. Theoretically at least, the correlations between the RPC's and average single-crosses should tend to be higher than the others since with random pollination the RPC's should be a composite of all possible single-crosses.

The results of the experiment with the late group where the parents and progenies were included both in space-planted plots and in broadcast plots show that the two methods may give different evaluations. Parent MIV-14 and its polycross progenies behaved quite differently, compared to the others, in the two methods of planting. For forage yields in particular, broadcast plots should give the more reliable evaluations since grasses are generally seeded in solid stands for forage use.

Progeny testing for leaf spot and leaf rust in orchardgrass may not be necessary; however, such data would ordinarily be obtained in conjunction with yield tests. This data would be a desirable supplement to that obtained from the parents.

It was easier to detect differences in disease susceptibility among the progenies in broadcast plots than in space-plantings. This may have been because the conditions in solid stands were more favorable for the spread and development of the leaf diseases or because it was easier to make comparisons from plot to plot where the plant variation was, in effect, averaged out in the broadcast plots.

In observing the disease resistance of the material, susceptibility to leaf rust was accompanied by resistance to *Stagonospora* leaf spot and vice versa. High susceptibility to both diseases was not found but some entries appeared to be relatively resistant to both. The nature of the relationship was not studied but it possibly could be a linkage problem. On the other hand, it might have been a physiological reaction with rust infection masking or preventing heavy leaf spot infection even though the material possessed an inherent susceptibility to leaf spot.

The use of seedling vigor tests as a means of evaluating progeny performance should be studied further as a possible short cut in a breeding program. If some way of measuring seedling characters can be devised that will correlate with field response, material could be screened much faster. The relationship between the seedling vigor and the field results of the seeded portion of the late group gave a certain amount of encouragement. The greenhouse tests were conducted in the fall under shortening day lengths. Perhaps a spring or summer trial would give results more consistent with those in the field.

SUMMARY

Methods of evaluating combining ability were studied using seven early and five late maturing orchardgrass clones. Progenies from a wide polycross of 112 clones, restricted polycrosses of the 7 and 5 clones, and single-crosses plus tiller plots of the parents were used in the testing. The early group was planted in broadcast plots and the late group in both broadcast and space-planted plots. Seedling vigor of the progenies as measured by growth in a greenhouse was compared to the field performance.

Considering yield, significant correlation coefficients were obtained in relating polycross and single-cross progenies to the parents, wide polycross progenies to restricted polycross progenies, and 1951 performance to 1952. There was considerable variation among the single-crosses for the respective parents indicating the expression of specific combining ability. The evaluation of the late parents differed in the two methods of planting both through parental yields and progeny yields. It appears that broadcast seedings are more desirable for testing than spaced plantings.

For height, the relationships among the parents and progenies were very similar to yield. Height was significantly correlated with yield.

Differences in susceptibility to leaf diseases were found. Susceptible parents produced susceptible progenies in all cases. Except for the correlations for the restricted polycross progenies for leaf spot, the correlation coefficients among the progenies and parents were highly significant. Differences in susceptibility were more easily detected in broadcast plots as compared to spaced plants.

Significant correlation coefficients were obtained for seedling top growth with seedling tillering and height. Relationship to field performance was obtained only with the broadcast plots of the late group.

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Association Between Diastatic Power and Certain Visible Characteristics and Heritability of Diastatic Power in Barley¹

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IT IS a well established fact that diastatic power is a major criterion of malting quality in barley. Diastatic power has been shown to be (2, 4, 7) a strain or varietal characteristic, and therefore, barley breeders can select strains which have a consistent relative activity for this enzyme. One of the major obstacles in selecting barley strains with a desired diastatic power is the lack of an easy method for evaluating this characteristic in the early generations of a barley cross. Even the ferricyanide method for determining diastatic activity in barley grain, developed by Anderson and Sallans (1), is too laborious to be used on the large number of segregates that need to be analyzed in a barley improvement program. Selection for good agronomic barley strains with desirable diastatic activity would be greatly facilitated if an association could be established between certain morphological characters and high or low diastatic power.

Den Hartog and Lambert (3) studied the association between diastatic power and yield, bushel weight, and floret fertility, all of which are considered to be multigenically determined. They found several significant correlations but they were of low magnitude. There is some popular belief that blue aleurone barley varieties are lower in malting quality than white aleurone strains. However, this fact has been refuted by isogenic line studies.³

The study reported herein is an attempt to determine if associations do exist in barley between diastatic activity and certain morphological characteristics whose mode of inheritance is known. The morphological characteristics were selected to represent one gene in each of the first five barley linkage groups (6).

MATERIALS AND METHODS

In order to determine if an association existed between diastatic activity and certain visible characteristics known to be determined by a gene which was already mapped, a number of crosses were made between low and high diastatic activity barley varieties in which certain visible characteristics segregated. In each cross, strains of barley homozygous for the two contrasting classes of the particular visible character were selected in the F₃ generation and analyzed for diastatic activity. By comparing the mean diastatic activity of the two classes, it was possible to distinguish any association between a given characteristic and diastatic power. The associations in all cases were with the marker gene rather than the chromosome.

The barley variety, O.A.C. 21, characterized by high diastatic activity, was crossed with a series of varieties having low diastatic

power. The parents low in diastatic activity were selected such that when crossed with O.A.C. 21 the resulting progenies would segregate for one monofactorial characteristic gene in each of the first five linkage groups. The barley linkage groups, visible characteristics studied, and crosses representing each linkage group are given in the following table:

Linkage Group	Visible characteristic segregating	Cross
I-----	2-row vs. 6-row	Alpha × O.A.C. 21
II-----	Black vs. white hulls-----	Dorsett × O.A.C. 21
III-----	Naked vs. covered kernels	C.I. 1370 × O.A.C. 21
IV-----	Blue vs. white aleurone	O.A.C. 21 × Mars
V-----	Rough vs. smooth awns	O.A.C. 21 × Mars

Since dominance was involved in each case except 2-row vs. 6-row it was necessary to grow the material in F₃ progeny rows in order to distinguish the 2 homozygous classes of each segregating character. Each plot consisted of 1 row, 16 feet long. The seed harvested from homozygous⁴ F₃ rows and parental selections, which were also grown in 1-row plots, 16 feet long, was ground to pass through a 20-mesh sieve and diastatic activity was then determined on each sample according to the method of Anderson and Sallans (1). Each sample was analyzed in duplicate or until the determinations agreed on titration to within 0.3 ml. of sodium thiosulphate. A standard variety was included as a check with each set of determinations. The difference between the mean diastatic activity of the two homozygous classes of segregates from a cross was tested for significance by a "t" test.

In order to compare naked with hulled barley seed the means of the *naked kernel* parent and the *naked kernel* progenies were adjusted for hulls using 13 as the average percentage of hull on a 6-row barley (8).

RESULTS

Association of Diastatic Power and Visible Characteristics

The means of diastatic activity in degree Lintner (L°) and the "t" values for each of the progeny classes and the parents are given in table 1. In all five cases the parents differ significantly in diastatic activity, with O.A.C. 21 being the highest in each comparison. It is evident from the "t" test for progenies that there is an association between diastatic activity and the 2-row vs. 6-row characteristic. However, the progeny of the 2-row group had the highest mean diastatic activity, in contrast to expectation. If some genes in linkage group I of the O.A.C. 21 parent contributed to high diastatic activity, it would be expected that the segregates of the 6-row group would have a higher mean diastatic activity than the 2-row group. To explain the results obtained, it must be assumed that the chromosome which carries the 2-row gene in the Alpha parent contributes a great deal of diastatic activity while the comparable chromosome in O.A.C. 21 contributes relatively little. The average background of germ plasma in the two classes of progeny should be approximately equal and any difference between the two groups in diastatic activity would be the contribution from

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³ Personal communication from Dr. G. A. Wiebe.

⁴ "Homozygous" refers only to the gene being studied.

Table 1.—Diastatic power in L° of parental varieties and classes of segregates from several barley crosses.

Generation	Chromosome group									
	I		II		III		IV		V	
	Alpha × O.A.C. 21		Dorsett × O.A.C. 21		O.A.C. 21 × C.I. 1370		O.A.C. 21 × Mars		O.A.C. 21 × Mars	
	2-Row	6-Row	Glumes		Kernels		Aleurone		Awns	
			Black	White	Covered	Naked	Blue	White	Rough	Smooth
Parents*										
N	12	12	12	12	12	12	12	12	12	12
M	183.06	215.13	163.89	215.13	215.13	186.20	215.13	141.15	215.13	141.15
t	3.37**		5.61**		3.41**		8.58**		8.58**	
Pure Breeding Progeny										
N	30	30	30	30	5	5	33	30	32	31
M	211.09	166.48	163.42	169.36	145.73	150.71	143.17	151.32	151.29	128.44
t	6.10**		0.85		0.55		1.37		3.12**	

* N = Number of selections or lines analyzed.

M = Mean.

t = t-value of the "t" test.

** Significant at the 1% level.

genes located in linkage group I. This can be illustrated by arbitrarily assigning numerical values for diastatic power to the genes in each parent. If it is assumed that the genes in linkage group I of O.A.C. 21 contribute 10 L°, the genes for diastatic activity in linkage group I of the Alpha parent contribute 55 L°. In this case the expected diastatic activity in progeny of the 2-row group would be 211 L° and the diastatic activity of the 6-row group would be 166 L° which fits exactly the values obtained. Irrespective of the validity of this explanation the data show that genes for determining diastatic activity are very definitely found in linkage group I in the Alpha × O.A.C. 21 cross.

As indicated by the "t" test, no association of diastatic activity was found between black vs. white hulls, covered vs. naked kernels, or blue vs. white aleurone. Since the number of progenies involved in the covered vs. naked kernel comparison were very small, this was not a critical test. The absence of association in linkage group IV is very interesting because there is a belief among some maltsters and brewers that white aleurone barley varieties are better for malting quality than blue ones. The data in this study would at least indicate that the malting quality characteristic, diastatic power, is not one of those which is associated with either blue or white aleurone. If malting quality is associated with this characteristic some criterion other than diastatic power must be responsible.

The data in table 1 indicate that there is an association between diastatic power and the rough vs. smooth awn characteristic in linkage group V. The rough awn class has a higher mean diastatic activity than the smooth. This would be expected if the O.A.C. 21 linkage group V carries genes for high diastatic activity.

The data given here indicate that there are genes in linkage groups I and V which contribute to high diastatic activity of barley. It may be found in other sets of crosses that there are also associations between genes in linkage groups II, III, and IV and diastatic power. However, in the crosses involved here no such association was obvious. If the genes determining diastatic activity work on a straight additive basis, we must assume that either a large portion of these genes are located in linkage groups VI and VII which were

not investigated in this study, or the genes contributing to diastatic activity were similar in the parents involved in the studies of linkage groups II, III and IV. According to the data presented the average contribution of linkage group V to diastatic power in the O.A.C. 21 parent was 23 L°, if the contribution from the Mars variety is considered to be zero. This figure represents a sizable part of the diastatic activity of O.A.C. 21.

Heritability of Diastatic Power

The heritability values for diastatic activity of the barley grain are given in table 2. They correspond to what Lush (5) describes as being in the "broad sense." In other words the genetic variance obtained by subtracting the mean parental variance from the total progeny variance contains not only additive genetic effects but also those due to dominance and epistasis. However, since the data used herein were collected from F₃ progenies the epistatic and dominance effects were materially reduced from the usual case when this method is applied to the variability among F₂ plants. The following formula was used in determining the heritability percentages:

$$\text{Heritability \%} = \frac{\text{Variance of progeny} - \text{Mean variance of parents}}{\text{Variance of progeny}} \times 100$$

In the crosses which showed no significant differences in diastatic power between the two selected classes, all of the strains were used as a random sample in the calculation of the heritability percentage. However, in those crosses showing a significant difference in diastatic power between two

Table 2.—Heritability percentages of diastatic power in barley.

Cross	Total variance	Genetic variance	Heritability %
O.A.C. 21 × Mars	676	231	34.2
Dorsett × O.A.C. 21	720	220	30.6
Alpha × O.A.C. 21	802	361	32.5
Mean			32.4

selected classes, it was necessary to calculate the variance within each class and then pool them in order to find the heritability percentage. Such was the case with the rough and smooth awn types in the O.A.C. 21 $\times$ Mars cross. Otherwise, there would have been introduced an artificial variance created by the differences between the means of the two classes. This method of analysis may lead to an underestimation of heritability since the complete range of variability of the linkage group in which selection is practiced does not enter into either class.

The heritability percentages for diastatic power ranged from 30.6 to 34.2 in the three barley crosses with a mean of 32.4. These values are not extremely high but, nevertheless, they do indicate that considerable progress could be made in selecting for high diastatic power among barley strains in the F_3 generation. Also worthy of note is the uniformity of the heritability percentages from the different crosses. Generally heritability values calculated by this method are not so consistent.

DISCUSSION

Barley data presented herein indicate that it should be possible to select strains early in the improvement program with certain morphological characteristics with assurance that the selected lines will be better for diastatic activity than a random sample. Such was the case in rough vs. smooth awn in the O.A.C. 21 $\times$ Mars cross, where the rough awn class of segregates had a mean diastatic activity significantly higher than that of the smooth awn class. (However, there are enough smooth awn commercial varieties to show this does not exclude the possibility of developing a smooth awn variety with desirable diastatic power.) In a cross between rough and smooth awn varieties, knowledge of the diastatic activity of the parents would tell the breeder whether to select rough or smooth awn segregates to obtain a favorable ratio of high diastase types. Of course, association demonstrated between diastatic power and the rough vs. smooth awn character might work to the breeder's disadvantage if it were desired to combine the smooth awn character from a low diastase parent with the high diastatic activity from a rough awn parent.

The association between the 2-row vs. 6-row character and diastatic power is of very little importance to barley breeders in the North Central States since the maltsters in this region prefer the faster germinating 6-row types. However, such an association could be very important to European barley breeders where the predominant malting type is 2-rowed. Thus, the association between the 2-row vs. 6-row character and diastatic power would be equally useful whether a 2-row or 6-row variety were desired, particularly if the association were one of relatively close linkage rather than pleiotropy.

Before any set rules can be established for barley breeders, relative to the association between known morphological characteristics and the association with diastatic activity, it will be necessary to run more linkage studies such as the one reported here. It may be found with future studies that the determination of diastatic activity is very closely allied with only a few of the seven linkage groups known in barley. Also, any future study should probably be conducted with different genes from those used herein, since it may be possible to miss linkages which actually exist. If the segregating characteristic were determined by a gene located near the end of a chromosome and a gene or genes for diastatic activity were located at the opposite end the two would probably appear to segregate independently.

SUMMARY

In a study to determine whether there was any association between diastatic activity in barley grain and known morphological characteristics, it was found that diastatic activity was associated with the rough vs. smooth awn character determined by a gene located in linkage group V. No associations were found between diastatic activity and the black vs. white hulled character determined by a gene in linkage group II, the naked vs. covered kernel character of linkage group III, or the blue vs. white aleurone character of linkage group IV. There was an association between diastase activity and the 2-row vs. 6-row characteristic determined by a gene in linkage group I. Of unexpected occurrence was the fact that the 2-row segregates had a significantly higher mean diastatic power than the 6-row types. Heritability values ranging from 30 to 34% were obtained for diastatic power.

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Pfeffer's Studies of the Root Growth Pressures Exerted by Plants¹

William R. Gill and G. H. Bolt²

THE pressure exerted³ and work performed by roots during growth are important considerations in evaluating the effect of soil physical properties on plant growth. Data on experiments to measure such pressures appear in a paper by W. Pfeffer, "Druck und Arbeitsleistung durch Wachsende Pflanzen" published in *Abhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften*, 33:235-474, 1893. Since this paper is absent from American soils literature the following review is presented to add to the data and to stimulate further interest in such measurements.

The basic principle of Pfeffer's measurements of root pressure was to encase a portion of the root of a seedling plant in a plaster of Paris block in order to provide a base against which the growing root could exert pressure to move a second block that was cast around the exposed tip or side of the root. Movement of the second block would compress a calibrated spring providing a measure of root elongation or expansion and the pressure exerted by the root. Figure 1 shows the arrangement of Pfeffer's apparatus.

Measurement of Axial Root Growth Pressure

To determine the axial pressures of growing roots with this arrangement, (figure 1 (a)), a pot P filled with moist excelsior M, was fastened to a stand S. The lower portion of the root was embedded in a plaster of Paris block A which was anchored securely by the plaster of Paris collar, which extended into the pot through the bottom hole, as shown by the white oval area in the pot. The root tip R extended through block A into a shallow hole in a second plaster of Paris block B. Block B was firmly secured to a glass disk D which was in turn connected with the stand S through compression spring F. The adjustment of screws E permitted the adjustment of the initial tension in the spring F. Two indicator needles I were mounted on the spring to permit a direct measurement of the compressed spring with the aid of a cathetometer.

To prepare a plant for axial pressure measurement, a seedling was placed in the pot filled with excelsior with the root extended 15 to 30 mm. through the bottom hole. The pot was then inverted and a paper cylinder with a radius of about 1 cm. placed around the root. The height of the cylinder was cut so that approximately 5 to 8 mm. of the root still extended above the cylinder. A plaster of Paris mixture was poured into the cylinder, flowing down into the pot through the bottom hole forming a collar within the pot to bind block A to the pot. Then a glass plate, with a hole comparable to the size of the root, was covered with wax paper and pressed over the root tip, permitting the tip to extend upward through the glass and paper. When block A was hard, the glass and paper were removed and replaced by a very thin piece of paper similarly provided with a hole. The plaster of Paris block B was poured on top of this paper, thus separating blocks A and B by a very small gap G, corresponding to the thickness of the thin paper. Results of measurement of axial root growth pressures secured by this method are given in table 1.

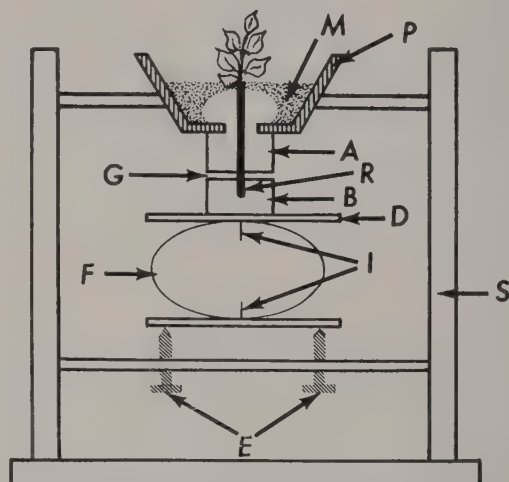


Fig. 1(a)
Pfeffer's apparatus for measuring axial root pressures

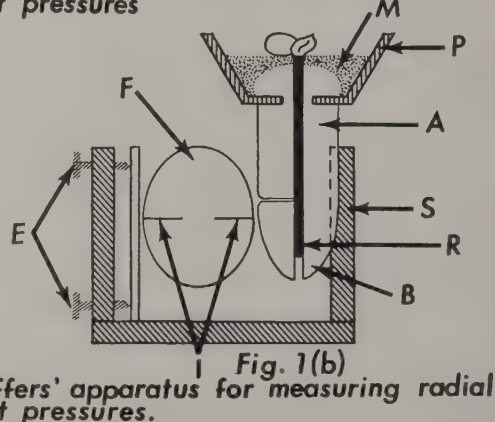


Fig. 1(b)
Pfeffer's apparatus for measuring radial root pressures.

FIG. 1.—(a) Pfeffer's apparatus for measuring axial root pressures. (b) Pfeffer's apparatus for measuring radial root pressures.

Measurement of Radial Root Growth Pressure

Radial pressure measurements were performed with a modification (figure 1 (b)) of the original apparatus. In this case the plaster of Paris block A not only surrounded the upper part of the root but also laterally enclosed half of the lower part of the root throughout the length of the root. Results of radial root growth pressure measurements secured with this apparatus are shown in table 1.

Pfeffer's Discussion of Pressure Measurements

Pfeffer believed that roots are a proper subject for pressure studies with plants since they do not require light and exert pressure on objects in the growth medium.

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³ The term "root pressure" should be avoided in this case since this term is presently applied by plant physiologists to a different phenomenon. The roots of some plants absorb water from the soil and exude it into the stems under pressure independent of any transpiration effects by the upper portion of the plant. This pressure has been termed "root pressure" and is used extensively in the botanical literature. As a suitable term "root growth pressure" is suggested which may be accompanied by such adjectives as axial and radial.

In order to reach maximum values in the axial direction, a root must be securely anchored and completely confined in the radial direction. In nature this could not always be true; hence a bending of the root instead of a buildup of axial pressure might occur. For this reason, pressures recorded in table 1 were considered as the maximum values since both side support and enchainage in the experiments were of sufficient magnitude.

Pfeffer believed that plaster of Paris blocks had no bad effect on root growth. To determine the effect of aeration on root growth under his conditions, he sealed a root in a plaster of Paris cylinder from which all oxygen was removed, and found that it maintained the same growth rate over a 24-hour period as a root in water containing oxygen.

The method of calculating the pressure was based on effective root area determined by measuring the cross section in the hole of the block. This is shown as the area of the root in table 1. Over an extended period, lateral growth would take place between the two blocks. This larger root cross section was the area shown under experiments lettered B in table 1. Coupled with the spring compression, the area provided the means to calculate the root pressure. Table 1 indicates that roots exerted pressures of 10 atmospheres or more when resistance was present on all sides. Pressures were exerted in both radial and axial directions, but rates of pressure buildup were not the same in the two directions. Axial pressure appeared greater than radial pressure. A relationship was believed to exist between them since experiments 5A and 5B indicated that radial pressure buildup would increase materially if the axial growth was impeded.

As the root met an external resistance, data indicated that the pressure would build up approximately asymptotically to a constant value. Since the total effective area in the radial direction greatly exceeded that of the axial direction area, the total force exerted in the radial direction under natural conditions would be many times larger. This is evidenced by the splitting action of roots in cracks in rocks, etc.

Mechanism of the Pressure Development

Pfeffer considered osmotic pressure in a free cell to be entirely balanced by wall pressure. If, on the other hand, the cell were confined by other tissues or external pressures, osmotic pressure would then be balanced by wall pressure plus external pressures. If the cell were to exert maximum pressure on its surroundings, the wall pressure would have to be reduced to zero. Data showed that actual pressure build-up by roots, could be increased by either a release of wall tension through growth of the cell walls or by an actual increase in the osmotic concentration within the cell. In a very thin cell wall, Pfeffer believed that actual growth did not contribute to the pressure, but merely permitted a transfer of internal pressure to external resistance. He considered that, if the turgor pressure were fully balanced by the exterior resistance and growth continued, there could be a folding of walls within the root. This folding would not be inhibited by the turgent condition of the cell.

To determine if the plaster block influences the osmotic concentration of a root, Pfeffer grew roots of seedling plants in plaster of Paris and in excelsior. Results showed that the osmotic concentration of the cells of beans grown in plaster of Paris increased, while those of corn did not. It would then appear that both of the mechanisms could be effective in some plants.

The actual measurement of the turgor pressure of the root cells was determined by the plasmolytic method. Roots were placed in a series of KNO_3 solutions immediately after taking them from the growth medium. Incipient plasmolysis as estimated by microscopic length measurements was used as the criterion of turgor pressure measurement. Additional evidence that the pressure development was brought about through growth of the cell wall was supplied by placing corn roots in a plaster of Paris block with one side exposed. If the root was placed in a solution of KNO_3 at this time, the tip shrank away from the block. If on the other hand, the root remained in the plaster of Paris 2 or 3 days before it was placed in KNO_3 , it would not shrink away. When it was removed and placed in water, a swelling took place, always more pronounced closer to the tip where the new cells would have formed by cell division, but which would only need to elongate. This was interpreted to mean that growth had taken place to prevent the root from shrinking since it had already shown the osmotic concentration did not increase in corn when embedded in plaster of Paris. In order to separate swelling from growth when the tissues were placed in water, the water was kept near freezing to prevent growth. Results of these experiments are shown in table 2.

Table 1.—Axial and radial pressures developed by roots.

Experiment No.	Axial Pressures				Radial Pressures				
	Duration of Experiment	Distance from tip	Cross sectional area of root	Pressure developed	Duration of Experiment	Condition of the root tip	Effective zone of root. Location and length	Lateral area	Pressure developed
	hours	mm.	mm. ²	atm.	hours		mm.	mm. ²	atm.
<i>Faba vulgaris</i>									
1	70	6.2	3.4	7.04	167	Confined	0-8	29	6.11
2	72	5.0	3.7	7.70	120	Confined	0-5.5	10.5	4.61
3	36	4.0	3.7	10.67	168	Confined	0-5	7.5	6.11
4	192	3.5	2.6	9.70	144	Confined	0-6.6	12.2	4.30
5A	94	0.0	1.13	19.36	164	Confined	7-15.7	15.8	5.50
5B	94	4.8	2.01	10.44	237	Free-7.5	-----	17.1	3.90
<i>Zea mays</i>									
6A	71	2.6	1.13	24.94	118	Free-7.5	0-11.2	11.0	6.59
6B	71	2.6	2.52	11.18	—	—	—	—	—
7A	34	2.3	1.54	12.39	—	—	—	—	—
7B	34	2.3	2.00	9.53	—	—	—	—	—
<i>Vicia sativa</i>									
8A	94	2.2	0.31	13.33	—	—	—	—	—
8B	94	2.2	0.5	8.26	—	—	—	—	—
<i>Aesculus hippocastanum</i>									
9	117	3.2	4.9	6.65	—	—	—	—	—

Table 2.—Growth of *Vicia faba* roots in gypsum casts.

Root	a*			b*	
	Mm. 2-5.66	Mm. 5.66-10.69	Mm. 10.69-15.14	Mm. 17-5.16	Mm. 5.16-9.55
Zone observed (tip = zero)					
Length before encasing in gypsum.....	127	117	103.5	116	102
Length in 6% KNO ₃ after 54 hours in gypsum.....	126	116	103.5	116	102.5
Length in water.....	143	122	104.0	136	106.5
Length when returned to 6% KNO ₃	126	116	103.5	116.5	102
Shrinkage.....	% 11.9	% 4.9	% 0.48	% 14.7	% 3.9

* Different roots.

It was thus shown that the external pressure resulted from the release of tension in the cell walls. Because pressure build-up was dependent on the growth of the cell wall, the pressure build-up against exterior resistance was a slow process, and maximum values could conceivably be reached only after 2 or 3 weeks. In general, a high percentage of the maximum value was reached in 2 or 3 days.

Growth Rate Against External Resistance

When a root was grown against a resistance, the rate of growth was found to be zero until the cell tension had been released sufficiently to overcome the resistance. After this point, the growth rate in general was found to be constant and, up to a certain point, independent of the magnitude of the external resistance. This period of building up, during which the wall tension was released, could be seen as an induction period. The existence of such an induction period made later measurements of the work performance rather difficult.

Exterior Work Performed by a Growing Plant

Since work performed results from the application of force over a distance, its value would be zero when either the force or the distance was zero. A plant growing in a medium such as water without resistance would exert zero force, while the distance would become zero if the exterior resistance was higher than the maximum pressure developed by the root. The root would perform work at intermediate values of the exterior resistance. A maximum work value was believed to occur at a point probably between one-half and two-thirds of the maximum resistance which could be overcome by the root. It was noted that the growth rate, at lesser values of exterior resistance was by no means proportional to the external resistance which probably accounted for a rather sharp maximum in work performance.

To measure work performance, root growth was followed in a homogeneous plastic medium of clay or gelatin in which different external resistances were made possible by variation of the moisture content. Resistance of the medium was evaluated by a penetrometer with a tip similar in shape to the root. Data are shown in table 3.

The rate of root growth in the slurry having a resistance of 1 gram was comparable to the rate of growth in water. The physical resistance of the clay was considered the important factor in root growth since Pfeffer believed aeration was equal in both cases. Considering that the root would not elongate until its induction period was complete, Pfeffer recalculated his data. In the axial pressure measurement investigations, bean roots required 6 to 7 hours to build up pressure against 100 gms. If this induction period was subtracted from the growth time, the theoretical increase could be added to the roots grown in the clay, enabling a comparison of growth on a 24-hour basis. The length of 12.9 mm. taken from table 3 when multiplied by the factor 24/18 in the case of a 6-hour induction period gave a calculated growth of 17.2 mm. which was essentially the same as that of the root in the slurry where no induction period occurred. The total work done by the root indicated in table 3 was 17.4 gm mm in the slurry and 1,290 gm mm in the 18.3% clay. As a comparison, burning $\frac{1}{4}$ mgm. starch would be equivalent to 1 calorie or

Table 3.—Influence of external resistance on rate of growth and work performance.

	Moisture content of a homogeneous clay	
	18.3 Percent	Slurry
Soil resistance to penetrometer.....	100 gms.	1 gm.
Growth of roots in 24 hours.....	12.9 mm.	17.4 mm.
Work performed (force $\times$ distance).....	1290 gm.mm.	17.4 gm.mm.

about 42,000 gm mm equivalence of work. Thus the work performed by the root in this case was very small and would require only a small part of 1 mgm. of starch.

Pfeffer considered that in nature a plant would deviate from its path in coarse-grained soils to go around solid resistance; thus the pressures exerted by a root would be less than pressures measured with a penetrometer. In fine-grained homogeneous mediums, the relationship between root penetration and penetrometer results appeared to be quite good.

Stem Growth Pressures Developed by Grass

Modifications of the apparatus shown in figure 1 were used to determine pressures exerted by other parts of the plants. In general, the results showed that axial pressures of the stems were of the order of magnitude of 7.5 atmospheres and radial pressures were about 5.5 atmospheres. The static moment of nodes ranged from 120 gm cm to 500 gm cm.

Conclusions from Pfeffer's Study of Pressures Developed by Growing Roots

Pfeffer's elaborate and well conducted experiments show the magnitude of pressures exerted by plant roots against external resistances encountered in the soil. These values form the only set of data available at this time.

Since the root has plastic properties, its path will generally be along the line of least resistance. Therefore, high values of axial pressures exerted are only encountered if the root is sufficiently confined in its radial directions.

The observation that wrinkling or folding of the cell walls of the root takes place when the root encounters unsurmountable external resistance suggests a possible diagnostic method of interpreting impeding properties of the soil in terms of the plant itself.

The calibration of homogeneous plastic media with a penetrometer for the evaluation of root growth against resistance appears to be another worthy line of approach.

The Response of Four Varieties of Alfalfa to Spring Clipping, Intervals Between Clippings, and Fall Clipping in the Yakima Valley¹

J. A. Jackobs and Donald L. Oldemeyer²

SEVERAL investigators (1, 2, 4) have shown spring-clipping, frequent cutting, and cutting at certain critical periods in the fall to be detrimental to alfalfa in the Midwestern states. However, the results of a management study reported by Jackobs (3) indicated that such management practices have little or no effect on the vigor and productivity of irrigated alfalfa in the Yakima Valley in south central Washington. The climate in the Yakima Valley is characterized by low rainfall and high light intensities; the ability of alfalfa in that area to withstand management treatments that are detrimental in the Midwest may be due to differences in such climatic factors and differences in soils.

Since Ladak was the only variety used in the initial study in the Yakima Valley, the question arose whether or not the results would be the same with other varieties. Results of such a study are reported here.

MATERIALS AND METHODS

A field on the Roza Unit of the Irrigation Experiment Station, Prosser, Wash., was selected for this experiment. The soil is Ritzville very fine sandy loam and varies in depth from 4 to 6 feet. The field was first irrigated in 1946, and the following crops were grown: 1946, lima beans; 1947, sweet corn; 1948, navy beans on one half of the field and vetch on the other.

Alfalfa was seeded May 5, 1949. The two replicates located where navy beans were grown in 1948 were successfully established, but the seeding following vetch failed and was replanted on Aug. 24, 1949.

The field was irrigated about once a month, using 24-hour applications of water in rills 3 feet apart. A 2½-inch stubble was left when a plot was cut. Yields were determined from a mower swath cut through the middle of the plot. All yields are given on an air-dry basis.

Main plots, 30 by 60 feet, consisted of 6 treatments including 3 cutting intervals both with and without spring clipping. Subplots consisted of 4 varieties of alfalfa: Ladak, Buffalo, Turkistan 19300, and Ranger. On Oct. 10 one half of each variety sub-plot was cut. The treatments within each division were randomized and there were four replications.

The cutting schedules were so arranged that the spring-clipping was made on May 1. Plots cut at 25-day intervals were cut first on May 26; the 30-day interval plots on June 1; and the 40-day interval plots on June 9. In this way the 5th cutting of the 25-day interval treatments, the 4th cutting of the 30-day interval treatment, and the 3rd cutting of the 40-day interval treatment all fell on Aug. 30. The late fall harvests were made on Oct. 10.

The cutting schedules outlined above were followed in 1950 and 1951. In 1952 all plots were cut on the same date at each of 3 cuttings. Differences in yield obtained in 1952, with the exception of those due to variety, are considered to be due to the residual effects of the previous management treatments.

At the conclusion of the experiment, stand ratings were taken by counting the number of crowns falling under a 16-foot transect.

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EXPERIMENTAL RESULTS

The yields of the four varieties of alfalfa with the various management treatments are given in table 1. An analysis of variance indicated that there was only one significant interaction in the course of the experiment between spring-clipping and interval-between-cutting in 1951.

SPRING CLIPPING

Clipping alfalfa on May 1 in 1950 and 1951 definitely decreased seasonal yield even though the weight of clipping was included. However, spring clipping did not appear to reduce plant vigor permanently, because in 1952, the plots that were spring-clipped in 1950 and 1951 produced within 0.35 ton per acre of those that had not been spring-clipped—a nonsignificant difference.

INTERVAL BETWEEN CUTTINGS

Increasing the number of cuttings per season from 3 to 4 and from 4 to 5 reduced seasonal yields an average of 0.77 and 0.96 tons per acre respectively. The 1952 yield data, however, did not indicate an appreciable reduction in plant vigor due to frequent cuttings.

FALL CUTTING

In 1950 an average yield of 0.40 ton of hay per acre between Aug. 30 and Oct. 10 increased the seasonal yield by this amount. In 1951, yields of the two treatments were nearly equal, indicating that the harvest in October compensated for the reduction caused by late cutting the previous fall. The 1952 data indicate a small but statistically significant reduction in plant vigor from cutting late in the fall. Plots cut late in the fall of 1951 yielded 0.23 ton per acre of hay less in 1952 than those not cut after Aug. 30.

VARIETIES

When the various cutting treatments were repeated in 1951, there were significant differences among varieties. Ladak, the check variety, produced less than the other varieties. The difference between Ladak and Turkistan only approached significance.

SPRING-CLIPPING × INTERVAL BETWEEN CUTTING INTERACTION IN 1951

The difference between the spring-clipped and check plots in 1951 was not the same for different cutting intervals. Table 2 shows the yields of the six cutting treatments and the difference in yield between spring-clipped and check plots. It is apparent that the difference is much smaller when there was a 40-day interval between cuttings than when the interval was 25 or 30 days.

EFFECTS UPON STANDS

Ratings of the stands in the fall of 1952 showed no detrimental effect resulting from the management practices. Full stands remained throughout all the plots.

Table 1.—Seasonal yields of four varieties of alfalfa under various cutting treatments at the Irrigation Experiment Station, Prosser, Wash., Tons of air-dry hay per acre.

Variety	Spring clipped	Not spring clipped	Interval between cuttings, in days			Fall cut	Not fall cut	Var. av.
			25	30	40			
1950								
Ladak	6.01	7.19	5.63	6.70	7.47	6.74	6.46	—
Buffalo	6.56	7.68	6.11	7.13	8.12	7.40	6.84	—
Turkistan	6.34	7.39	5.84	7.04	7.72	7.11	6.62	—
Ranger	6.17	7.38	5.98	6.74	7.61	7.02	6.52	—
Average	6.27	7.41	5.89	6.90	7.73	7.07	6.61	—
1951								
Ladak	5.49	6.15	5.14	5.61	6.72	5.84	5.81	5.82
Buffalo	5.83	6.77	5.59	6.14	7.18	6.32	6.29	6.30
Turkistan	5.55	6.56	5.25	5.79	7.07	6.05	6.02	6.03
Ranger	5.80	6.55	5.49	6.04	7.00	6.24	6.12	6.18
Average	5.67	6.51	5.37	5.90	6.99	6.11	6.06	—
1952								
Ladak	5.98	6.31	6.22	5.96	6.26	6.09	6.18	6.14
Buffalo	5.91	6.29	6.14	6.14	6.06	5.95	6.26	6.10
Turkistan	5.82	6.23	5.94	6.02	6.14	5.84	6.22	6.03
Ranger	6.10	6.38	6.12	6.16	6.45	6.15	6.32	6.24
Average	5.95	6.30	6.10	6.07	6.23	6.01	6.24	—

DISCUSSION

In general, the results substantiate the previous work reported by Jackobs (3) in which only one variety was used. The main differences were the more pronounced effect of spring clipping and a smaller effect from fall cutting. Hay yields of the alfalfa were materially reduced by the more frequent cuttings during the seasons in which the clipping treatments were applied.

In 1951, the second year of differential management, yields of the fall-clipped plots were about the same as from those that were not fall-clipped. Apparently fall cutting causes reduced yields during the early part of the following season. However, this was compensated for by the yield obtained from the late cutting. The late fall clipping treatment did cause a significant reduction in yield in 1952 when all plots were harvested on a three cutting schedule. The additional yield from a fall cutting was not included in the seasonal yield, and there was no compensation for the lower yields in the early part of the season.

The significant interaction of spring-clipping $\times$ interval between cuttings for yield might be expected. With the 40-day interval, there was a longer period for the replenishment of root reserves before plots were cut the second time. Consequently, the reduction in subsequent yields was less.

Reductions in yields because of the treatments could be attributed mainly to depleted root reserves and not to a permanent reduction in plant vigor. No significant residual effects were found in 1952, except for the fall cutting treatment. No effects upon stand were noted.

SUMMARY

Four varieties of alfalfa were grown for hay production under various clipping schedules which included spring clipping; 25-, 30-, and 40-day intervals between cuttings; and fall clipping. The schedules were arranged so that the date of the last cutting of all plots, except the fall cutting, was Aug. 30. The treatment schedules were followed in 1950 and 1951. In 1952, all plots were harvested uniformly with three cuttings to measure any residual effects that resulted from previous treatments.

Table 2.—Interaction of spring clipping $\times$ interval between cuttings. Yield in tons per acre.

Interval between cutting (days)	Spring clipped	Not spring clipped	Difference
25	4.83	5.90	1.07
30	5.33	6.46	1.13
40	6.85	7.13	.28

Significant reductions in yield resulted from more frequent clipping. In 1951, the average seasonal yield for the 25-day interval of clipping without a spring-clipping was 5.90 tons per acre as compared with 7.13 tons per acre for the 40-day frequency without spring-clipping, a reduction of over 1 ton per acre by cutting 5 times rather than 3.

By adding the spring clipping treatment to the 25-day interval, the yield was further reduced to 4.83 tons per acre. With the 40-day interval, the yield was 6.85 tons per acre. Spring clipping caused significant reductions in yield, with the effect being more pronounced with the shorter interval between clippings. This interaction was significant.

No significant effect of fall clipping on seasonal yield was found until 1952, the year following the discontinuance of the treatments. The fall clipping in 1950 did not influence yields in 1951, but the treatments did give a significant reduction in 1952 when all plots were treated alike.

Significant differences among varieties were obtained only in 1951, and no variety $\times$ treatment interactions were found. The only residual effect due to treatments was that of fall clipping.

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Response of Soybean Strains to 2,4-D and 2,4,5-T¹

H. A. Fribourg and I. J. Johnson²

DURING the past 5 years a series of investigations has been conducted at the Iowa Agricultural Experiment Station to determine the differential response of a wide range of genotypes in corn, oats, and soybeans to several growth regulating compounds. These studies have been made in the laboratory using the root suppression test and in the field with standard spray techniques. Results of these studies, including the cytohistological effects of 2,4-D on apical meristem of oats and the inheritance of differential response to 2,4-D in corn, have been published (1) (3) (4) (5) or are currently in press. Many studies have been reported, largely in the abstracts of the North Central Weed Control Conference, on varietal response of crop plants, using varieties or hybrids that are commercially grown, to determine tolerance limits for chemicals now used as herbicides.

The present investigation with soybeans, however, was designed as an exploratory study to determine (from an agronomic point of view) the differences that might exist among a group of introductions from the Orient. It was believed that this source of material, from which present soybean varieties originated either as selections or from crosses among these selections, might represent a wider range in genetic diversity than could be found among more recently developed varieties adapted in maturity to the cornbelt. Discovery of even a few strains with a relatively high degree of tolerance might therefore prove to be of value to the soybean breeder as parents for use in developing agronomically desirable strains that could tolerate dosage rates effective in selective weed control. Such strains might also be of value to the physiologist for further studies on the causes of injury to plant tissues by growth regulators.

An attempt also was made in this study to determine the relationship between the response to 2,4-D of strains tested in the seedling stage under greenhouse conditions using the single droplet technique (2) and their field response to spray application of 2,4,5-T as measured by reduction in seed yield. Previous studies with soybeans³ had shown a poor relation between the root suppression test and field response to 2,4-D as measured by dry weight of leaves. Rapid tests to screen a large number of selections for differential response would be a valuable aid in a breeding program.

MATERIALS AND METHODS

From among nearly 2,000 introductions available⁴ from the Orient, a group of 200 was chosen to represent a cross-section from China, Manchuria, Korea, and Japan within the maturity

range adapted at Ames, Iowa. An attempt was made to increase the limited seed during the winter, 1951-52 in cooperation with the U. S. Department of Agriculture field station at Brawley, Calif., but failed due to severe freezing temperatures. An increase was successfully made in 1952 at Ames, Iowa, and at Columbia, Mo., in cooperation with the Regional Soybean Laboratory. Among the original 200 strains, 16 were too low in germination to provide adequate seed.

Screening tests with the micro-droplet technique were made in the greenhouse during the winter, 1952-53 using only 2,4-D since 2,4,5-T could not be effectively used on soybeans. Soybean seedlings do not show a marked response when treated with 2,4,5-T using the micro-droplet technique. After a large number of preliminary studies to determine optimum concentrations, wetting agents, solvents, manner of application and methods of evaluating effects, the following procedure was adopted.

Five soybean seeds per strain were planted in a soil-sand mixture in each of three 4-inch clay pots previously coated externally to reduce moisture evaporation. After the seedlings had emerged to full unifoliate leaf stage and the central leaflet of the first trifoliate leaf was almost fully expanded and before the second trifoliate leaf had begun to unfold, all seedlings not at this stage of growth were removed by cutting at the soil surface. If available, one seedling at this exact stage of growth was left per pot. Of the three pots per strain, one was designated as the check and the remaining two each were treated with a micro-droplet (0.013 to 0.014 cc.) of an aqueous solution containing 5% tergitol and 50 and 100 ppm. concentration respectively acid equivalent of 2,4-D. The single droplet was placed near the midrib of the central leaflet midway between the base and the tip. Plants were then permitted to continue growth at greenhouse temperatures of 70 to 75° F. for 2 weeks, or until the fourth trifoliate leaf was expanding. The effect of 2,4-D treatment was recorded as a percentage reduction in leaf size by visual comparison with the check for each of the first (treated), second and third trifoliate leaf. Greatest reduction usually occurred to the second leaf; rarely did it extend to the fourth leaf. To facilitate routine testing, 20 strains were included in a group and one replication (3 pots) of each planted every third day. A total of 40 strains were tested in 10 replications before high greenhouse temperatures in late spring appeared to adversely modify results. In a few strains, when sufficient plants of uniform stage were not available, the means are based on less than 10 but not less than 7 replications.

For the field studies, all strains with sufficient seed (184) and Hawkeye, a standard, were planted in a randomized split-split-plot design of four replications with maturity groups (group 0 to group 4) as whole plots, treatments (check, 1/10 and 1/4 pound acid equivalent of 2,4,5-T per acre) as sub-plots and strains within treatments as sub-sub-plots. Plots were single-row 11 feet long with 36 inches between rows. Wide alleyways (5 feet) were provided between ranges. All strains within maturity groups were sprayed at the same date when the majority of the strains were at full bloom. Spray application was made across the rows about 12 to 18 inches above foliage height with a special plot sprayer, tractor mounted, at 8 gallons per acre under 40 pounds pressure. Data recorded include stage of bloom when sprayed, date ripe, and seed yield. It was necessary to hand-pick threshed seed from treated plots to remove stem pieces from brittle stalks that could not be removed by screens.

RESULTS AND DISCUSSION

Because the data reported herein are based on a large number of introductions, none of which is a named variety, the major portion of results will be presented in frequency distributions without reference to specific P.I. numbers. Detailed data on some of the most tolerant and most susceptible strains are summarized in table 4.

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³ Williams, James Henry. Crop variety response to exogenous growth regulators. I. Suppression of root growth by 2,4-dichlorophenoxyacetic acid. Iowa State College Library. 1950.

⁴ Seed was obtained in 1951 through the courtesy of Dr. M. G. Weiss, then Senior Agronomist in charge of soybeans investigations, U.S.D.A.

Table 1.—Frequency distributions of relative response of soybean strains when treated with 1/10 pound per acre acid equivalent of 2,4,5-T. (Data adjusted to regression of response on maturity date).

Maturity group	Yield in percent of check												Total	Mean
	5	10	15	20	25	30	35	40	45	50	55	60		
0	—	—	1	2	1	0	1	1	—	—	—	—	6	25.6
1	1	0	1	4	4	6	8	3	1	3	2	4	37	35.3
2	—	3	11	20	24	11	9	7	9	2	1	—	97	27.9
3	—	—	1	2	8	10	6	2	3	2	3	—	37	33.0
4	—	—	1	0	2	0	1	0	0	1	1	—	6	34.9
Totals	1	3	15	28	39	27	25	13	13	8	7	4	183	30.6

Field Studies

From an agronomic point of view the difference in response of strains to field spray applications of 2,4,5-T may be of greatest interest. These results are shown as frequency distributions in table 1.

Among the 184 strains, one was a creeping, viny type and has been omitted from the summary. Data are presented for response only at 1/10 pound per acre because a very high proportion of those treated at 1/4 pound per acre were so severely damaged that a normal distribution was not obtained. Response of selected strains at the higher concentration is shown in table 3. From the analysis of variance, made separately for each maturity group, the interactions of strains $\times$ treatments exceeded the 1% level for each group, indicating that strains did not respond alike to 2,4,5-T applications.

Although the data show the results of spray application in terms of yield reduction, the actual response also was manifest in other ways that are difficult to measure in quantitative terms. The most obvious response (see figure 1) was extreme malformation of plants within a few days after treatment. It was not possible to measure varietal differences in foliage reaction accurately. Pods failed to set from flowers in bloom when sprayed. The most obvious reason for differential response apparently was the greater ability of some strains to recover by production of new floral primordia. The main stem and branches that had developed up to the time of treatment remained twisted, greatly enlarged, and exhibited a large number of root primordia on the stems. Stems remained green in color when non-treated plants were beginning to mature (see figure 2) but were more brittle than the latter. Originally, it was hoped that the differences in maturity between the check and treated plots might serve as an additional measure of tolerance (or ability to recover) but the abnormally high temperatures with moisture deficiency in late September ripened all strains in the treated plots within a few days and thus reduced potential spread in maturity date.

As indicated above, damage to flower buds was one of the major causes of injury. All strains within a maturity group were treated on the same day; and because the original classification for maturity apparently was not accurate, there was a strong likelihood that differences in blooming might have affected varietal response. Correlations were therefore computed, within groups, between relative yield at 1/10 pound treatment and date of maturity (date ripe is highly correlated with date bloom and more accurate to record). These data, and regression coefficients are given in table 2.

All correlations were positive, indicating that the earlier strains were more severely damaged than the later maturing

Table 2.—Correlation and regression coefficients between relative yields of soybean strains when treated with 1/10 pound per acre acid equivalent of 2,4,5-T and date of maturity of the not treated check.

Maturity group	No. of strains	Correlation	Regression
Group 0	6	0.496	1.671
1	37	.284	1.837
2	97	.529**	1.363
3	37	.756**	1.395
4	6	.669	1.401

** Significant beyond the 1% level.

strains, and two exceeding the 1% level of significance. The regressions of relative response on date maturity were consistent for all groups. On the basis of these results, values for relative response were corrected to the regression values to adjust for differences in maturity among strains within groups.

It was of interest to compare the relative response of the most tolerant and most susceptible strains (treated at 1/10 pound per acre) with their relative response when treated with 1/4 pound per acre. Nineteen strains from the three upper and three lower classes in table 1 were chosen for this comparison. These data are shown in the frequency distributions in table 3. Although the range in relative response of the more tolerant strains at 1/4 pound varied from 20 to 55, several were moderately tolerant to this high concentration level. Nearly all of the more susceptible strains were very severely damaged. These results further emphasize the possibility of using the more tolerant strains as parents in breeding for greater tolerance to this growth regulator. By comparison, Hawkeye, a standard widely-grown variety had a relative yield of 34.0 and 17.1 when treated with 1/10 and 1/4 pound per acre.

Because relative tolerance as reported here is determined by yields of the check as well as treated plots, it was of interest to determine possible correlation between the yields of the check and relative tolerance. Only the 97 strains in maturity group 2 were used in this calculation, because of the large number of entries and their general adaptation in maturity to the location of this test. The correlation obtained was -0.249 , which, although relatively small, exceeded the 5% level of significance. Apparently there was no strong association between yielding ability and tolerance to 2,4,5-T.

Greenhouse Studies

The frequency distributions for relative leaf size of 40 strains treated by the microdroplet technique with 2,4-D is summarized in table 5. As expected, leaf size was reduced

Table 3.—Frequency distributions of relative response of 19 of the most tolerant and 19 of the most susceptible soybean strains (based on response at 1/10 pound per acre) when treated with 1/4 pound acid equivalent 2,4,5-T per acre.

Group	Yield in percent of check											Mean
	5	10	15	20	25	30	35	40	45	50	55	
Tolerant	—	—	—	2	6	4	1	4	1	0	1	31.8
Susceptible	15	3	1	—	—	—	—	—	—	—	—	5.2



FIG. 1.—Typical foliage response to 2,4,5-T within one week after application. Left center, a very susceptible strain. Right, a more tolerant strain.

more when treated at 100 ppm. than at 50 ppm. The range in response was very great and differences among strains were significant beyond the 1% level of significance from the analysis of variance made separately for each concentration. Although extreme care was used to select plants carefully at the same stage of development at time of treatment, the error variances were relatively high for this test. Because each replication consisted of only one plant, it is possible that part of this variability was due to genetic differences among plants since field and seed observations indicated that many introductions were not pure lines. More consistent evaluation also would require better temperature control following treatment than is usually possible under usual greenhouse conditions.

Of greatest interest was the relationship between response of the 40 strains when treated with 2,4-D by the microdroplet technique and field response to 2,4,5-T. As previously stated, soybean seedlings did not show a marked response when treated with 2,4,5-T using the microdroplet method. The correlations between relative yield (adjusted to regression) and relative leaf size were -0.292 at 50 ppm. and -0.356 at 100 ppm. Only the latter correlation was significant at the 5% level. The importance of these correlations is difficult to interpret. They may be due to failure of seedling foliage tissue and the entire plant to respond to treatment in a similar way, or they may be due to differential response of strains to the two growth regulators. Previous studies (3) have shown that soybean varieties respond in a similar way to 2,4-D and 2,4,5-T ($r = 0.76$) by the root tissue test but low correlations were found between response to 2,4-D and isopropyl N-phenylcarbamate (IPC).

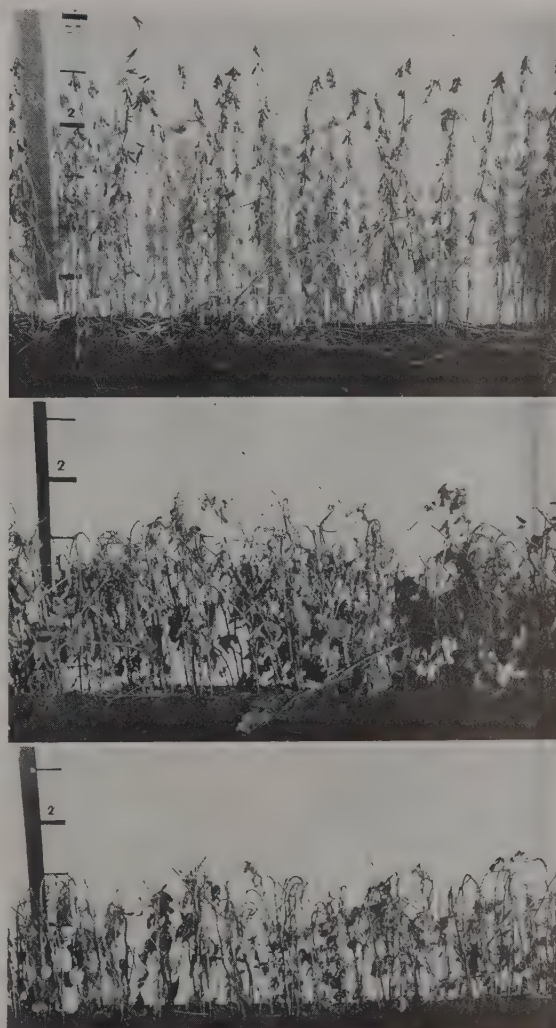


FIG. 2.—Mature plants of susceptible strain. Upper, not treated, center, treated at 1/10 pound per acre and lower, treated at 1/4 pound per acre acid equivalent of 2,4,5-T at full bloom. Note nearly complete lack of pods and short twisted stems.

The low negative correlations in the present study do suggest, however, that a screening test using 2,4-D is not an effective method for determining response to 2,4,5-T as measured by reduction in seed yield.

SUMMARY

1. A total of 183 strains of soybeans introduced from the Orient were tested to determine their response to 2,4,5-T as measured by reduction in seed yield at two rates of application, 1/10 and 1/4 pound acid equivalent per acre, in comparison with the check. Forty strains were tested for response to 2,4-D by the microdroplet technique in the greenhouse at the seedling stage of growth.

2. Highly significant differences were obtained among strains in response to 2,4,5-T. At the 1/10 pound rate about 10% of the strains showed a reduction in yield of only 40 to 50%; about 10% showed reductions of 85 to 95% in yield, and the remainder ranged between these limits. Only a few strains were tolerant at the higher concentration to the extent of yield reduction of 45 to 60%.

3. Highly significant differences also were obtained among 40 strains in response to 2,4-D applied as a microdroplet (0.013–0.014 cc.) to the first unifoliate leaf. Reduction in leaf size of the second leaf varied from 25 to 90% with 50 ppm, and from 40 to 95% with 100 ppm. concentration.

4. Negative correlations were obtained between yield reduction of strains treated with 1/10 pound per acre of 2,4,5-T and either 50 or 100 ppm. of 2,4-D by the microdroplet method.

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Table 4.—List of more tolerant and susceptible soybean strains, including yield in bushels per acre and date of maturity of check treatment and yield in percent of check when treated with 1/10 and 1/4 pounds per acre acid equivalent of 2,4,5-T.

P.I. Numbers	Check treatment		Relative yield in % of check	
	Bu. per acre	Date ripe	1/10 lb./A.	1/4 lb./A.
Tolerant strains				
68806.....	42.2	Sept. 20	50.4	43.4
70084.....	38.6	16	56.5	32.4
70516.....	40.9	16	58.0	39.4
73587.....	38.7	18	57.8	40.1
84681.....	47.2	20	53.8	38.8
87574.....	31.6	21	60.7	56.6
88357.....	40.5	16	51.4	26.9
87620.....	43.4	23	53.1	24.4
70218.....	32.2	26	53.2	27.6
70229.....	31.0	30	53.0	29.7
88459.....	37.8	28	49.0	30.2
88292.....	24.9	29	48.8	36.5
Susceptible strains				
63271.....	34.1	Sept. 16	12.8	5.6
84810.....	44.6	20	14.2	4.5
68472.....	45.9	17	12.3	2.0
68564.....	44.4	17	14.2	2.0
68587.....	47.0	22	10.6	3.6
70559.....	43.6	21	11.5	4.1
79583.....	36.9	20	12.9	3.5
79726.....	48.4	17	13.2	3.1
79848.....	44.5	21	14.8	4.5
84637.....	39.8	21	14.1	2.3
Hawkeye....	41.2	21	34.0	17.1

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Table 5.—Frequency distributions of relative response of 40 soybean strains when treated with 50 and 100 ppm acid equivalent of 2,4-D applied with the microdroplet technique to the first trifoliate leaf.

Concentration of 2,4-D	Leaf size of the second leaf in percent of the check															Mean
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	
50 ppm.....	—	1	2	4	3	4	2	5	8	5	4	1	0	0	1	38.7
100 ppm.....	1	1	3	7	4	8	5	6	2	2	0	1	—	—	—	30.1

The Effect of Freezing and Thawing on Structure of the Soil Surface¹

C. W. Domby and Helmut Kohnke²

THE soil surface deserves special attention in studies of soil structure. It is physically the most active zone in the soil profile, where the temperature, moisture, and air content change more widely and rapidly than at any other depth. Although most studies of soil structure are conducted during warm seasons, probably the greatest and most rapid changes in structures of the soil surface, other than those produced during tillage, result from alternate freezing and thawing of certain soils while wet. One reason that these changes in soil structure are of immediate economic concern is that they may kill crops by heaving, a process which frequently is as important as winter-killing by actual freezing of plant tissue or smothering by ice sheets.

REVIEW OF LITERATURE

Bouyoucos and McCool (2) and Taber (10, 11) discussed the mechanisms of ice crystal growth and heaving of soils, and emphasized that excessive heaving is dependent on water moving upward through the soil to the zone of freezing, and cannot be accounted for by the change in volume of water upon freezing. As water in the surface layer of soil freezes, the soil moisture tension greatly increases. Therefore, a tension gradient is created, and additional water moves up from the wet soil, where water is held at low tensions, into the freezing layer where it is held at high tensions. This process may continue until the pores in the surface layer of soil are not only filled by ice, but are enlarged by the ice accumulation, expanding and heaving the soil. Much of the more recent work related to heaving of soils, primarily from an engineering viewpoint, has been brought together in a symposium on frost action in soils (4).

Four major factors influencing the amount of heaving of soils discussed in the literature (2, 4, 5, 10) are:

- 1.—the availability of water in the soil and subsoil; 2.—the rate at which water can be conducted through the soil to the zone of freezing, primarily as a liquid; 3.—the rate of cooling of the soil; and 4.—the amount and effectiveness of insulators at the soil surface, including snow, grass, litter, mulches, etc. Maximum heaving would occur when there is abundant water in the soil and subsoil, in soils of relatively fine texture and high capillary conductivity, such as silt loam and very fine sand, when the soil freezes slowly, and when it is bare.

Although it is generally recognized that freezing and thawing affect the structure of many soils, no simple generalization can be made concerning this effect, which seems to depend on at least the following:

1. *The moisture content of the freezing and thawing soil* (6, 8).—If the soil is not too wet, its aggregation may be improved; if a very wet soil is frozen and thawed, even previously existing aggregates may be destroyed.

2. *The rate of freezing and amount of water left unfrozen* (6, 8).—When a soil is frozen slowly, ice is segregated into large layers or crystals, with appreciable amounts of unfrozen water in the soil between the crystals. If the moisture content of the soil was not too great, a desirable crumb-like structure may result upon thawing. When a fine-textured soil is frozen rapidly, ice is

uniformly distributed in small crystals through the soil; such a soil is likely to have a disaggregated structure when it thaws.

3. *Frequency of freezing and thawing* (1, 9).—Frequent freezing and thawing may be less effective in developing aggregation, or may be more destructive to aggregation, than occasional freezing and thawing.

4. *The soil texture and organic matter content* (1, 8).—Clay soils with high organic matter content seem most likely to be improved structurally by freezing and thawing; silty soils with low organic matter content seem most likely to be dispersed.

Because of the large number of possible combinations of the above factors, freezing and thawing could affect soil structure in many different ways. It is evident, however, that there is a strong similarity between those conditions which favor heaving of the soil and the conditions which lead to a breakdown of soil structure.

EXPERIMENTAL PROCEDURE

A series of small plots was established at the Agronomy Farm of Purdue University, near Lafayette, Ind., for studies of the structure of the soil surface. The soil was a Russell silt loam derived from glacial till, with good surface drainage and fair internal drainage. Treatments established during the summer of 1950 and continued until the summer of 1952 included bare soil, soil with two tons of oat straw per acre as a surface mulch, and soil under a straw mulch suspended on wire netting about 3 inches above the surface.

Periodic determinations were made of the bulk density and water-stability of the surface half inch and second half inch of soil. Stability of aggregation of 2 to 5 mm. fragments was determined by wet sieving using a method comparable to that of Bryant *et al.* (3), with results expressed as mean weight-diameters (12). Bulk densities and moisture contents of soil in the field, except when frozen, were determined with 13.6-ml. sampling cans about 1/2 inch deep.

The daily trends in moisture contents and bulk densities of the alternately freezing and thawing bare soil surface and of the underlying soil were studied during part of March, 1952. When the air temperature dropped to 20 to 25° F. at night, bare soil which had thawed during the previous day usually froze to a depth of about 1 inch. Under these conditions, the frozen soil surface in the morning had a structure and moisture content comparable to that which Post and Dreiblebis (7) described as having "concrete" structure. It was characterized by the presence of a large amount of ice uniformly distributed through the frozen soil, without large lenses, layers, or needles of ice, and with no apparent air space remaining in the frozen layer. In the mornings, blocks of the concrete-like frozen soil surface were cut out with a stiff-bladed knife in much the same way that a watermelon is "plugged". In some cases, these frozen blocks of soil were measured and their volumes calculated; in all cases, their moisture contents were determined gravimetrically. Close agreement was obtained between the bulk densities calculated from the measured dimensions and those calculated from the moisture contents, assuming that all pores were ice-filled.

In the afternoons, the bulk densities and moisture contents of the surface half inch of thawed soil were determined with the small sampling cans. Whenever samples of the soil surface were taken, moisture samples were also taken from just below the zone of daily freezing and thawing.

RESULTS AND DISCUSSION

General Effect of Winter on Structure of the Soil Surface

The greatest changes in structure of the surface of the Russell silt loam occurred during the winter. The effect of

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various treatments on the changes in water-stability of this soil are summarized in table 1. The mean weight-diameter of the water-stable aggregates in the surface half inch of the bare plots declined markedly during the first winter. The water-stability of the mulched soil declined during the second winter, presumably because partial decomposition of the mulch had reduced its effectiveness. Even during the first winter there were decreases in water-stability of the soil at a depth of $\frac{1}{2}$ to 1 inch under the mulch, but the bare soil had the greatest decrease in water-stability at this depth.

Increases in density of the surface of mulched as well as of bare soils occurred during the winter. The mean bulk densities (weight of solids per volume) of mulched as well as of bare soils increased from approximately 1.15 g. per cc. in September, 1950, to 1.35 gm. per cc. the following spring, with a loss of about half the volume of pores drained at a tension of 50 cm. of water ("large pores"). Soils which were loosened by tillage during the summer of 1951 became dense again during the following winter.

Diurnal Changes in Structure of the Soil Surface Caused by Alternate Freezing and Thawing

Large diurnal changes in structure as well as moisture content of the surface of this bare silt loam occurred as a result of alternate freezing and thawing during the early spring. During the process of freezing at night, sufficient ice accumulated in the surface layer to greatly reduce its bulk density and to cause heaving of the surface. The soil just below the zone of freezing and thawing, however, was drier in the mornings when ice had accumulated in the surface than in the afternoons when the surface had thawed and slumped.

Figure 1 shows the trends in air temperature and the resulting changes in moisture content and bulk density of the surface layer of soil on three bare plots during a portion of March, 1952. The diurnal variations in moisture content of the soil below the depth of daily freezing and thawing are also shown. It must be emphasized that the great diurnal variations in bulk density of the soil in the freezing zone (figure 1) are due largely to the changes in water content, not to the expansion of water in freezing. The latter could—in a soil saturated with water—account for not more than 5% bulk density changes.

Table 1.—Effect of surface cover on water-stability of Russell silt loam near Lafayette, Ind., September, 1950, to February, 1952.

Treatment	Depth inches	Sampling Date			
		Sept., 1950	April, 1951	Sept., 1951	Feb., 1952
Bare.....	0- $\frac{1}{2}$	1.21	0.37	0.48	0.22
	$\frac{1}{2}$ -1	1.46	0.30	0.48	0.20
Straw on surface.....	0- $\frac{1}{2}$	1.36	1.39	1.33	0.24
	$\frac{1}{2}$ -1	1.27	0.68	0.79	0.23
Straw 3 in. above surface.....	0- $\frac{1}{2}$	1.26	1.03	1.19	0.26
	$\frac{1}{2}$ -1	1.25	0.46	1.07	0.25

* Means of four replications.

Actually, decreases in bulk density of the soil up to 30% resulted from the accumulation of water—in ice form. The amount of ice accumulation and degree of expansion and slumping of the soil surface consistently differed on these three plots, even without apparent differences in the soils, topography, or previous treatment, and although the plots were within 50 feet of each other. Trends in soil moisture content and structure similar to those in figure 1 could be expected whenever this soil encountered a period of daily freezing and thawing while very wet. In Indiana, these conditions are more likely to occur during the spring than during the relatively dry fall.

Mulching with straw decreased diurnal changes in structure of the soil surface, probably because freezing under mulch was not so frequent as on bare soil, and also because less water froze under the mulch. Ice formed below the mulch was not as uniformly distributed through the soil as in the bare soil, and was sometimes present only as vertical needle crystals between the soil surface and the mulch, with no ice in the soil itself.

Appreciable daily variations in structure of the soil surface probably occur only during periods of alternate freezing and thawing, but it is evident that repeated freezing and expansion of the soil surface followed by its thawing and slumping results in marked winter changes in soil structure as well as in winter-killing of crops on some soils.

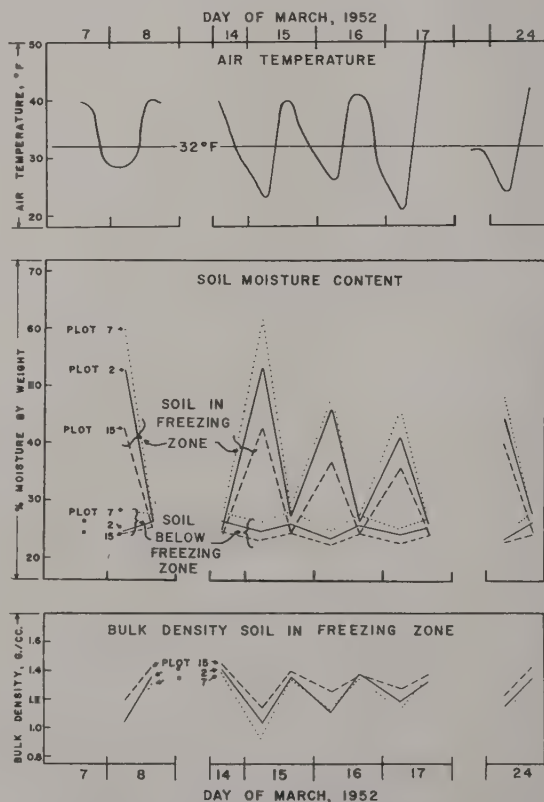


FIG. 1.—Trends in air temperature, soil moisture content, and in bulk density of the surface of three bare plots of Russell silt loam, during a portion of March 1952.

SUMMARY

Investigations of the structure of the surface inch of bare and mulched Russell silt loam were conducted near Lafayette, Ind., over a period of nearly 2 years. The greatest changes in structure of this soil occurred during the winter or early spring. The most rapid winter decrease in water-stability occurred where the soil was bare, but by the end of two winters most of the water-stable aggregates in the mulched soil also were broken down. Soil which was loose in the fall became compact during the winter, even where a surface mulch of 2 tons of straw per acre was present.

When this bare wet soil froze at night during the early spring, moisture from the underlying soil accumulated as ice in the freezing surface layer. This ice accumulation caused expansion of the soil in the frozen layer and upward heaving of the surface. When the soil thawed during the day, some of the excess moisture drained back into the soil below, and the soil surface slumped down again. The soil below the zone of daily freezing and thawing was driest when the surface was frozen, and was wettest after the surface had thawed.

Methods were described for determining the bulk densities of the frozen soil. The diurnal changes in moisture content and bulk density of the alternately freezing and thawing surface, and in the moisture content of the unfrozen soil below, during a portion of March, 1952, were shown graphically.

The similarity of the soil and weather conditions which favor heaving of the soil surface to the conditions which lead to winter breakdown of soil structure indicate a need for further investigation of the relation between soil heaving

and other changes in soil structure during the winter. The need for quantitative studies of the relationship between the heaving of the soil surface and the winter-killing of crops is also suggested.

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Variability in Letoria and Fulwin Oats¹

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STUDIES by Coffman and Stanton (3); Coffman, Parker, and Quisenberry (2); and Morey (9) have shown that oat varieties differ in degree of intra-variety variability. It has been generally recognized that varieties of the species *Avena byzantina* show greater intra-variety variability for plant and seed characters than *saiva* varieties. As a partial explanation of this, Garber and Quisenberry (6) report more natural crossing between *byzantina* varieties than between *saiva* varieties.

In heterosis studies, Coffman and Stevens (4) have shown that some varieties of oats influence the yield of F_1 progeny more than others. The variety Bond seemed to depress the yield in F_1 hybrids, whereas Markton and Victoria increased it. In some crosses, heterosis existed in kernel weight, height, panicle length, and total plant weight, whereas the culm number was usually decreased, as Coffman and Davis (1) have shown.

Hybrid progeny were frequently earlier in heading than the parents, according to Coffman and Wiebe (5). Owing to the earliness of the F_1 plants, these authors state, culms per plant and total plant weight seemed of little value as measures of hybrid vigor.

Genetic studies of quantitative characters present serious difficulties since the number of genes involved is usually large and the effect of single genes is usually small. One method of study, used in an attempt to overcome the difficulties, compares the variance of segregating and non-segregating material. Mather (8), working with oat data collected by Quisenberry, used the variance of the parents as an estimate of the environmental variance which he subtracted from the F_2 variance to get an estimate of the total genetic variance. This technique always raises the question of the genetic uniformity of the parents, since previous studies (2, 3, 9) have shown that certain oat varieties are not uniform. Poole and Grimboll (10), working with watermelons, and Powers (11), working with barley, have used the variances of non-segregating material as an estimate of the environmental portion of the variances in segregating material. Powers (11) added, however, that erroneous conclusions may be drawn in estimating residual genic variability by using parental data as an absolute measure of environmental variances, since the amount of variation due to the environment is not the same for all genotypes.

This study was one of a series designed to determine if the Letoria and Fulwin oat varieties differ in genotype for the six characters, viz.: height, culm number, seed number per plant, weight of seed per plant, weight per seed, and seed number per panicle.

MATERIALS AND METHODS

Letoria, released in 1941 from the North Carolina Experiment Station, is a selection from the cross between Lee and Victoria.

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Lee is classified as *Avena saiva* and Victoria is classified as *Avena byzantina*. Fulwin is a selection from Fulghum, released in 1941 from the Tennessee Experiment Station, and classified as *Avena byzantina*.

Fifteen crosses involving different pairs of parent plants in the two oat varieties, Letoria and Fulwin, were made in 1947. The F_1 seeds and the selfed seeds of the 30 parent plants were maintained separately. In the fall of 1948, seed from the 15 crosses and the seed from their respective parents were space-planted 4 inches apart in rows 12 inches apart and 16 feet long in a split plot design with 4 replications. The whole plots consisted of 2 F_2 rows from each cross bordered by rows of the specific parents of the cross, on each side. The height in centimeters, culm number per plant, seed number per plant, weight of seed per plant, weight per seed in grams, and seed number per panicle were determined for each of 20 randomly selected plants in each row.

EXPERIMENTAL RESULTS

Crosses.—Mean squares in table 1 show that the variation among Letoria parents was not significant in any of the six characters. On the other hand, there were significant differences among the 15 Fulwin parents for each character except number of seed per panicle, and also significant differences between the crosses in the F_2 population for each of the characters except yield.

Heterosis.—If it is assumed that heterosis exists when the mean of the progeny is significantly greater than the average of the parents, then heterosis in the progeny of these two varieties did exist for each character, as is indicated in table 2, which gives a test of significance between the average mean of the parents and the means of the F_2 's. The t-values shown in column 6 of table 2 are highly significant for each character.

Genetic Variability.—If the average of the within-row variances of the two parents is used as an estimate of the environmental contribution to the variance within the F_2 rows, then after subtraction of the within-parent variances from the within F_2 variance, an estimate of the total genetic contribution to the variance in the F_2 population is obtained.

Columns 2 and 3 in table 3 show the intra-plot variance of the parents and of the F_2 's, respectively, for all 6 characters. Column 4 gives the estimated genetic variance and Column 5 the estimated genetic variance of the F_2 's as a percent of the total F_2 variance.

DISCUSSION

The variability found in the Fulwin variety may stem from several possible origins. The variety may not have been homozygous at the time when it was released, or a mechanical mixture could have occurred with other varieties after it was released. There is still a possible third explanation. According to Huskins (7), there have been many reports of fatuoids (false wild oats) in the *byzantina* species. Apparently these fatuoids originate from non-homologous chromosome cross-overs. Therefore, if non-homologous chromosome cross-overs do occur and fatuoids result from such a cross-over, then it is reasonable to expect that such cross-overs could also bring about other changes. This supposition has been substantiated by Morey (9), who has investigated the morphological variability in the Clinton oat. This variability

Table 1.—Mean squares for 6 quantitative characters among the 15 Letoria and the 15 Fulwin parents and among the 15 F_2 populations.

Character	Letoria	F_2 's	Fulwin
Yield per plant in gms.	0.8057	0.9850	1.2325**
Height per plant in cms.	21.8655	113.9112**	125.0274**
Culm number per plant	3.4205	1.8247**	5.1151**
Number seed per plant	1611.0974	3657.1500**	4157.1560**
Weight per seed in centigrams	0.0271	0.0439**	0.0386*
Number seed per panicle	7.8954	54.0704**	29.3184

* Significant at 5% level.

** Significant at 1% level.

Table 2.—The mean of the parents, the average means of the parents, the means of the F_2 's, and a test of significance between the average parent means and F_2 means for the character studied.

Character	Letoria	Fulwin	Mean of both parents	F_2 means	t-values
Yield per plant	2.797	2.267	2.532	3.932	9.92*
Height in cm.	65.208	84.408	74.808	79.580	7.02
Culm number/plant	10.645	5.073	7.859	8.884	6.19
Seed number/plant	133.423	139.341	136.382	198.529	8.85
Weight/seed	0.021	0.016	0.018	0.019	4.95
Seed number/panicle	12.350	26.463	19.409	22.239	3.72

* $t_{0.05} = 2.14$ † $t_{0.01} = 2.97$

in the Fulwin variety emphasizes the fact that single plants or small samples of plants from the variety may not be representative of the variety.

The highly significant t-values in table 2 indicate that these two varieties had different genes for the characters studied, and that these genes combined in the F_2 's to give an increase in vigor for these characters. A question of interest is whether those gene differences are quantitative genes as such or whether some of the extra vigor is due to disease resistant genes which were combined in the F_2 's.

First of all, Letoria is resistant to crown rust, but susceptible to mosaic. Fulwin, on the other hand, is susceptible to crown rust but resistant to mosaic. The amount of rust on the susceptible parent and on the F_2 population was insignificant and no attempt was made to correlate rust readings with other characters. However, on one complete replication, the degree of mosaic infestation was determined. The plants were rated from 0 to 4, 4 being the most severe. The mean for F_2 's was 1.68 and for the Letoria parents was 2.43. Correlations were computed between the mosaic ratings and each of the six characters. They are as follows:

	Letoria	F_2 's
Mosaic $\times$ height	-0.203	-0.250
Mosaic $\times$ wt./seed	-.019	-.147
Mosaic $\times$ number seed/panicle	-.180	-.231
Mosaic $\times$ number seed/plant	-.014	-.097
Mosaic $\times$ yield	-.031	-.110
Mosaic $\times$ culm number/plant	.124	.109
5% r	0.113	0.088
1% r	.148	.115

Although these correlations are small they tend to indicate that as the mosaic was increased there was a corresponding decrease in expression of each character except culm number in both the Letoria and the F_2 populations. However, in spite of the depressing effect on the characters by mosaic,

the F_2 progeny exhibited heterosis for each character. This expression of heterosis may be due to the fact that the F_2 's were affected less by the mosaic than the average of the parents and/or that there were genetic differences between the two varieties other than disease resistance. The heterosis also indicates at least partial dominance in gene action at some of the loci where genotype of the two varieties differed.

In table 3, it would appear that the F_2 's had considerable genetic variation, especially for yield and seed number per plant, which were 62.8% and 59.2% respectively of the corresponding phenotypic variance. The estimated genetic variance for number of seed/panicle was 33.2% and for height and culm number about 18%. These estimates were obtained by using the average intra-plot variances of the parents as an estimate of the F_2 environmental variance. However, upon examining table 4, which gives the intra-plot variances of both parents and for the F_2 's, one may question the validity of direct comparison of variety and F_2 variances as a basis for estimating the genetic portion of the F_2 variance. It should be noted (table 4) that although yield and seed number per plant have larger intra-plot variance in the F_2 's than in either parent, one of the parents has a larger intra-plot variance for each of the other four characters than does the F_2 generation.

When the means (table 1) and the variances (table 4) are compared, a strong relationship is disclosed. For example, the intra-plot variance of culm number in the Letoria parent is about 22% greater than in the F_2 population. The culm number mean is also larger (about 13%) for the Letoria parent than for the F_2 population. This relationship holds for each of the four characters that were represented by larger intra-plot variances in one of the parents. On the other hand, for yield and seed number per plant, the intra-plot variances for the F_2 population were larger than for either parent, and the means of the F_2 's were also larger than either of the parents.

³ Although this assumption may not be entirely valid, it has merit. For instance, the correlations between means and variances for yield is 0.830, and for height, 0.997. The other characters have similar relationships.

Table 3.—Average intra-plot parent variance, intra-plot F_2 variance, estimated genetic variance in F_2 's, and genetic variance expressed as a percent of total F_2 variance.

Character	Intra-plot variance		Genetic variance*	Genetic variance as % of total†
	Parents	F_2 's		
Yield/plant	3.456	9.813	5.857	62.88
Height	120.126	146.655	26.529	18.08
Culm number	15.757	19.358	3.601	18.60
Number seed/plant	9001.799	22065.170	13063.371	59.20
Weight per seed	0.175	0.114	0.000	0.00
Number seed/panicle	87.496	131.050	43.554	33.23

* F_2 variance minus parent variance† F_2 variance minus parent variance $\times 100$
 F_2 variance

By assuming a linear relationship* between means and variances the environmental variances observed in the varieties were adjusted to the F_2 means as follows:

$$\text{Adjusted } V_e = V + (M_2 - M) \frac{(V' - V)}{M' - M}$$

Where M = the smaller parent mean M' = the greater parent mean M_2 = the F_2 mean V = the variance of the parent with the smaller mean V' = the variance of the parent with the greater mean

For example, in case of height

$$V_e = 78.25 + (79.6 - 65.2) \frac{(162.00 - 78.25)}{(84.4 - 65.2)} = 141.06$$

The results from this procedure are presented in table 5.

The estimates of the genetic variances as a percent of the total variance (when parent environmental variance is adjusted to F_2 means) presented in table 5 are considerably less than those presented in table 3. No doubt the genetic variance estimates presented in table 3 are biased upward

by the large means of the F_2 's. The adjusted genetic variance estimates presented in table 5 may well be biased downward and, if so, are conservative estimates.

Primary interest in these estimates centers on the estimate of the genetic variance for yield. In light of the heterosis expressed for yield and the amount of genetic variance estimated (29% of the total F_2 variance), one may conclude that these two varieties differ genetically with respect to yield.

SUMMARY

The progeny from 15 crosses between Letoria and Fulwin oats were studied. The sample of Fulwin oats used in this study was found to be variable for the characters yield, height, culm number per plant, weight per seed, and seed number per plant. On the other hand, the sample of Letoria was uniform for these characters. This information indicates that material obtained from a mating between single plants from each of the two varieties may not be representative of the average for the cross of those varieties.

The F_2 exhibited heterosis in all characters studied, and for yield and seeds per plant they exceeded both parents.

Genotypic variance of all characters was estimated (1) by the difference between F_2 variance and the mean of the par-

Table 4.—Intra-plot variances of Letoria, Fulwin, and the F_2 's and their standard deviation.

Character	Letoria	Fulwin	F_2 's
Yield	4.060 $\pm$ 0.249	2.860 $\pm$ 0.261	9.310 $\pm$ 0.649
Height	78.250 $\pm$ 4.340	162.000 $\pm$ 9.420	146.650 $\pm$ 6.180
Culms	24.640 $\pm$ 1.400	6.880 $\pm$ 0.730	19.360 $\pm$ 0.900
Seed/plant	7982.530 $\pm$ 484.000	10021.070 $\pm$ 755.000	22065.170 $\pm$ 1513.000
Weight/seed	0.226 $\pm$ 0.047	0.125 $\pm$ 0.043	0.113 $\pm$ 0.026
Seed/panicle	36.190 $\pm$ 3.000	142.800 $\pm$ 12.860	131.050 $\pm$ 8.170

Table 5.—Observed F_2 variances, average variance of parents adjusted to F_2 means, estimates of F_2 genetic variances, and the latter as a percent of the total F_2 variance.

Character	Total F_2 variance	Adjusted variance (V_e)	Estimate of F_2 genetic variance	Genetic variance as % of total
Yield	9.32	6.62	2.70	29
Height	146.65	141.06	5.59	4
Culms	19.36	19.02	0.34	2
Seed/plant	22065.00	30403.00	0.00	0
Weight/seed	0.113	0.185	0.00	0
Seed/panicle	131.05	110.91	20.14	15

ent variances and (2) by the same difference but with the mean parent variance adjusted to the F_2 means assuming a linear relation between means and environmental variances. The latter estimates suggest considerable genotypic variance in the F_2 yield and seeds per panicle but little if any in the other four characters studied. However, the observation of significant heterosis in all characters leaves no doubt that the parent varieties differ in genotype for all traits and hence, that genotypic variance for all traits in the F_2 is inescapable.

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Linkage Relationships of the Martin, Hussar, Turkey, and Rio Genes For Bunt Resistance in Wheat¹

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THE identification and cataloging of germ plasm resistant to pathogenic organisms are basic to the successful development of resistant varieties. This may be done either on a varietal or gene basis and by the use of either pure or mixed cultures of the pathogene. However, for greatest utility such an index should be reduced to its simplest component, that of gene-race interaction. With this information available, the development of resistant varieties resolves itself to the proper combination of the available germ plasm to provide for maximum race coverage. Information on the linkage relationships of the genes involved is necessary to determine whether the desired combinations can be obtained.

Briggs and associates (1, 2, 6, 11, 16)³ have identified seven genes conditioning resistance to race T-1 of *Tilletia caries* (DC.) Tul. Two of the genes in combination provide protection against at least 25 of the 31 races presently isolated (10). Although four of these genes are located in one linkage group (9, 16),³ sufficient crossing-over occurs to permit their combination into one variety if desired. In this paper additional information on the linkage relationships of these genes is presented. The genetics of resistance of two varieties, California 3028 and California 3029, which contribute information to some of the linkage values under consideration is also reported.

MATERIALS AND METHODS

Stanford (16) reported linkage between the R gene for bunt resistance in Rio and the T gene in Turkey 3055. However, his data did not permit a reliable estimate of the recombination value

between them. Subsequently, test crosses were made to provide this information. The F_1 hybrid of Rio (Rt) $\times$ Turkey 3055 (rT) was crossed with the susceptible varieties, White Federation, Poso, and Big Club. The F_2 progenies of these crosses were tested for their reaction to bunt.

The resistant varieties, Calif. 3028 and Calif. 3029, were crossed with the susceptible variety Baart and with the resistant varieties Martin, Turkey 3055, Rio, and Selection 1403, which are testers for the M, T, R, and H genes, respectively. Although a small F_2 population of each cross was inoculated, the genetical analysis was based on F_3 progeny tests.

All of the material tested for bunt reaction was inoculated by dusting the seed with chlamydospores of race T-1 of *T. caries*. This collection has been used in all previous studies at this station. The progenies of all crosses, except with the tester varieties Martin, Turkey 3055, Rio, and Selection 1403, were grown in duplicate rod rows. Only single progeny rows of the test crosses were grown. Eighty seeds were planted in each row. Resistant and susceptible parental checks were included at regular intervals. The plants were pulled when nearly mature and classified as diseased or healthy.

Calif. 3028 and Calif. 3029 are selections of Turkey wheat obtained from W. J. Sando, Agronomist, United States Department of Agriculture. They have been highly resistant to race T-1 over an 11-year period with only one infected plant having been found in each variety.

The genetics of the resistance in Rio and Turkey 3055 wheats have been reported previously by Stanford (16) and Briggs (6), respectively.

RESULTS

Crosses Between (Turkey 3055 $\times$ Rio) F_1 and White Federation, Poso, and Big Club

These crosses were designed to measure the frequency of parental and recombination gametes produced by the F_1 hybrid of the cross Turkey 3055 (Tr) $\times$ Rio (tR). If crossing-over occurred, four types of zygotes would be expected in crosses with susceptible varieties having the recessive allele at each locus, i.e. $Trtr$, $tRtr$, $TRtr$, and $trtr$. The frequency of these types would provide an estimate of the recombination value between the T and R genes.

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³ E. P. Baker. Inheritance of resistance to bunt (*Tilletia caries* (DC.) Tul.) in hybrids involving Turkey wheat selections 10095 and 10097. Ph.D. thesis, University of California, Berkeley, Calif., 1949.

Briggs (6) and Stanford (16) have shown that the average infection in progenies segregating only for the T gene or the R gene is 40.0 and 45.0%, respectively. Although no information is available on the amount of bunt to be expected in progenies segregating for the T and R genes in the coupling phase, it should be less than for those in which the genes occur alone. Progenies from the double recessive combination would be fully susceptible.

Six hundred thirty-four F_2 progenies from the cross (Turkey 3055 $\times$ Rio) $F_1 \times$ White Federation and 76 F_2 progenies with Poso as the susceptible parent were tested for smut reaction in 1948. Unfortunately, the level of infection was extremely low, with an average of 42.1 and 41.5% bunt in the White Federation and Poso checks. The distribution curve of the F_2 progenies showed no clear cut minima which could be interpreted as distinguishing genotypic classes. Consequently, no attempt was made to estimate linkage from these data.

All of the lines in which the infection was 65% or more of the two adjacent check plots in 1948 were retested in 1949. The distribution of parental plots and F_2 progenies by 5% infection classes is given in table 1. The range of infection in White Federation was from 65.1 to 87.3% with an average of 78.3%.

A definite minimum in the distribution curve occurred at the 55 to 65% infection level, which approximated the lower range of the parental plots (table 1). If this minimum in the curve is accepted as the separation point between the heterozygous and susceptible families, 51 families would then be classified as susceptible. The average infection of these lines was 74.4%, which was in close agreement with the value of 78.3% for the susceptible checks. The 1949 results were correlated with those obtained in 1948 to determine whether any of the susceptible progenies might have been missed by not retesting the entire population. None of the 25 lines retested whose infection was between 65 to 70% of the adjacent checks in 1948 was found to be susceptible in 1949. This was considered sufficient evidence that all of the lines in which the infection was less than 65% of the adjacent checks in 1948 were heterozygous and not susceptible.

The distributional pattern of the lines with less than 60% infection in 1949 showed no clear cut minima which could be used to separate the three other genotypes expected in progenies of this cross. The 51 susceptible lines represented 8.16% of the total F_2 population of 625 families and is a measure of the frequency of the recombination gamete tr produced by the F_1 hybrid. The recombination value between the T and R genes, as calculated from these data, was $16.32 \pm 1.46\%$.

Similar interpretation of the data (table 1) from the cross with Poso as the susceptible parent gave a recombination value of $18.42 \pm 4.44\%$.

Four hundred twenty-three F_2 progenies of the cross (Turkey 3055 $\times$ Rio) $F_1 \times$ Big Club were tested for their reaction to bunt in 1954. The distributions of the parental plots and F_2 progenies by 5% infection classes are given in table 1. The range of infection in Big Club, the susceptible variety, was from 71.8 to 98.9% with an average of 90.8%. A definite minimum in the distribution curve was evident at the 75 to 85% infection level. This was accentuated by the prominent declension in the curve from the 62.5% class to the 77.5% class. The mid-point of this minimum, 80.0% infection, was considered to be the point of separation between the segregating and susceptible families. This was in

agreement with the minimum obtained by Stanford (16) with comparable levels of infection. Although some of the susceptible progenies might be expected to have less than 80% infection as suggested by the distribution of the parental rows, it is believed that they would be offset by the presence of segregating rows with more than 80.0% infection. The exact proportion of each type within the minimal classes could be determined only by additional tests. The significant shift in the point of separation of the segregating and susceptible progenies between the tests in 1949 and 1954 can be accounted for by the higher level of infection resulting from environmental conditions extremely favorable for bunt development in 1954. This is evident when comparing the distribution of the parental checks as well as the average infection for the 2 years (table 1).

Twenty-eight progenies, or 6.6% of the total population, had more than 80.0% infection and were considered to be homozygous susceptible. The average infection of these lines was 86.8% which is in close agreement with the value of 90.2% for the susceptible check rows. The recombination value between the T and R genes calculated from these data was $13.24 \pm 1.65\%$.

The estimate of linkage from the combined data provided by the 3 crosses was $15.18 \pm 1.57\%$. The non-significant χ^2 value in the tests for homogeneity ($\chi^2 = 1.0639$ with 2 d.f., $P = 0.7 - 0.5$) indicated that the three sets of data were in agreement in supporting this value.

Crosses Involving Calif. 3028 and Calif. 3029

The distributions by 5% classes for bunt infection of the parental checks and the F_2 progenies of the various crosses involving Calif. 3028 and Calif. 3029 are presented in table 1. Both varieties were highly resistant with an average infection of 0.02% and 0.03% for Calif. 3028 and Calif. 3029, respectively. The range of infection in Baart, the susceptible variety, was from 42.5 to 92.5% with an average infection of 67.3%.

The distribution curves of the F_2 progenies of the crosses with Baart appear to be divided into three parts by definite minima at the 7.5 and 37.5% classes (table 1). The minimum at the 37.5% class coincided with the lower range of the Baart plots; consequently, all of the progenies with more than 37.5% infection were considered to be susceptible. The minimum at the 7.5% class appeared to separate the resistant and the heterozygous progenies. Since overlapping of the two types would be expected in the minimal class, half the progenies in the 7.5% class were arbitrarily assigned to each type. In the Calif. 3028 cross there were 48 resistant, 87 heterozygous, and 62 susceptible F_2 progenies. This suggested a 1:2:1 ratio which would be expected with monofactorial segregation. In the cross Calif. 3029 $\times$ Baart there were 60 resistant, 158 heterozygous and 60 susceptible progenies which also suggested a ratio of 1:2:1. Chi square tests for goodness of fit of observed to expected ratios gave P values of 0.2 — 0.1 and 0.1 — 0.05 for Calif. 3028 and Calif. 3029, respectively. The average infection of 16.7% and 16.8% in the heterozygous rows indicated dominance of expression. Consequently, the resistance of each variety can be ascribed to a single dominant gene pair.

No segregation occurred in crosses with the variety Martin, which is the tester variety for the M gene. In the cross with Calif. 3028 no susceptible plants were found among 408 F_2 plants or in 161 F_3 progeny rows involving 7374 plants. Likewise, none was found in a population of 306 F_2 plants and in 148 F_3 progeny rows in the cross with Calif. 3029.

The absence of segregation indicated that the resistance of these two varieties was conditioned by the M gene or by one closely linked with it. In a population of 148 F_3 progenies, one segregating row would have been expected ($P = 0.95$) with a recombination value of 2.0% or greater. Since the distributional pattern of the F_3 progenies in the crosses with the susceptible variety Baart was the same as that obtained by Briggs and other (1, 3, 4, 15) with crosses involving the M gene, it can be assumed that this gene is present in the two varieties.

Susceptible F_3 progenies occurred in all crosses with Turkey 3055, Rio, and Sel. 1403 which are tester varieties for the T, R, and H genes, respectively. In analyzing these crosses for linkage relationships, those progenies within the range of the susceptible Baart checks were considered susceptible. However, in some cases, there appeared to be some overlapping of the heterozygous and susceptible rows. This might be expected since the mean infection in the rows segregating for the tester genes may approach 40 to 50% under favorable conditions.

The observed number of resistant and segregating:susceptible F_3 progenies in the hybrids with Turkey 3055 agreed with the 15:1 ratio expected with independent segregation (table 2). In the hybrid Calif. 3029 $\times$ Turkey 3055 the distribution agreed equally well with the ratio expected for linkage between the M and T genes with a recombination value of 34.22% as reported by Briggs (9). However, in the Calif. 3029 cross there was an excessive number of susceptible progenies. From an examination of the distribution

of these progenies (table 1), it was noted that 15 of the 21 progenies classified as susceptible, or 71.4%, fell within the 42.5 to 52.5% infection classes, whereas only 11.8% of the susceptible checks were within this range. Since these classes are within the infection range of the progenies heterozygous for the T gene, misclassification could account for the high number of susceptible progenies obtained.

Stanford (16) reported linkage between the R and M genes with $28.1 \pm 6.16\%$ recombination. The cross-over value obtained in the cross Calif. 3028 $\times$ Rio was found to be $27.6 \pm 6.16\%$. Although the segregation obtained in the hybrid between Calif. 3029 $\times$ Rio agreed with that expected with independent segregation ($P = 0.20 - 0.10$), there were only nine susceptible progeny when 15 were expected. The combined estimate of linkage from the data of the two crosses was $33.5 \pm 6.14\%$ which was within one standard error of the value obtained by Stanford.

Linkage between the M and H genes was suggested in the crosses with Sel. 1403. There were 3 susceptible progenies in the cross with Calif. 3028 and 4 in the cross with Calif. 3029, when 10 were expected in each cross. The deviation from the expected 15:1 ratio was significant with Calif. 3028 ($P = 0.05 - 0.02$) and approached significance with Calif. 3029 ($P = 0.10 - 0.05$). When the data from the two crosses were combined, the deviation was highly significant ($P = < 0.01$). The deficiency in these crosses of rows segregating for the H gene supports the evidence of linkage. Briggs (2) found the mean infection of rows heterozygous for the H gene was 44.2% with a range from 22.5

Table 1.—Distribution of parents, F_2 and F_3 progenies of the crosses named into 5% classes for bunt infection.

	Number of rows or progenies in 5% infection classes																				Total	
	0-5		5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95		95-100
	0	0.1-5																				
White Federation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	7	2	1	-	-	13
(Turkey 3055 × Rio)F ₁ × White Fed.	-	-	-	-	3	11	15	22	18	21	13	9	3	4	13	12	16	4	2	-	-	166*
Poso	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	3
(Turkey 3055 × Rio)F ₁ × Poso	-	-	-	-	-	-	5	9	2	4	0	2	0	1	1	3	1	1	-	-	-	29†
Big Club	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	4	6	8	3	-
(Turkey 3055 × Rio)F ₁ × Big Club	-	-	1	4	5	13	21	20	25	32	60	58	42	48	30	26	9	9	14	5	-	423
Calif. 3028	26	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27
Calif. 3029	24	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25
Martin	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Sel. 1403	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
Turkey 3055	8	5	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
Rio	7	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
Baart	-	-	-	-	-	-	-	-	-	1	5	5	10	10	20	17	10	11	1	2	-	92
Calif. 3028 × Baart	36	8	8	34	37	8	3	1	1	4	5	9	9	12	7	7	6	1	1	-	-	197
Calif. 3029 × Baart	46	10	9	51	65	31	4	2	0	2	5	6	13	10	8	7	6	2	1	-	-	278
Calif. 3028 × Martin	161	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	161
Calif. 3029 × Martin	148	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	148
Calif. 3028 × Turkey 3055	92	45	44	25	24	10	6	6	7	5	6	4	0	2	1	1	1	1	-	-	-	280
Calif. 3029 × Turkey 3055	88	62	40	15	11	9	3	6	4	0	1	6	2	2	1	0	0	0	-	-	-	250
Calif. 3028 × Rio	131	63	28	16	8	7	2	2	0	3	1	1	0	0	-	-	-	-	-	-	-	262
Calif. 3029 × Rio	99	47	41	23	11	8	4	3	1	2	3	2	1	1	-	-	-	-	-	-	-	246
Calif. 3028 × Sel. 1403	86	30	20	6	6	4	1	2	0	1	0	0	0	0	1	0	1	-	-	-	-	158
Calif. 3029 × Sel. 1403	89	27	12	8	4	4	1	1	1	1	1	0	1	1	0	0	0	-	-	-	-	151

* Total population = 634 lines tested in 1948; only those lines with an average infection of more than 65% of the susceptible checks were retested in 1949.

† Total population = 76 lines; see footnote above.

to 62.5%. In the two crosses under discussion there were only 21 F_3 progenies in a total population of 309 that had more than 20.0% infection and which could be considered either heterozygous for the H gene or homozygous susceptible (table 1). With independent segregation 3/16 of the total population or 58 F_3 progeny should be of these genotypes. This deviation was highly significant ($P = < 0.01$). Since considerable overlapping of progenies heterozygous either for the M gene or the H gene might be expected within the infection range of 15 to 30%, the estimation of linkage was based only on the identification of the susceptible progenies. A recombination value of $30.75 \pm 5.63\%$ was obtained from the pooled data. The inclusion of the H gene in the MXRT linkage group places five of the seven genes for bunt resistance on one chromosome.

DISCUSSION

The results of numerous investigations involving the linkage relationships of the genes conditioning resistance to race

T-1 of *Tilletia caries* in wheat have been published by Briggs and associates (9, 15, 16).⁴ Linkage between the M and T (9, 15), M and R (15, 16), and T and R (16) genes has been established. Heretofore, the H gene was considered to be independent of the others. In view of the evidence presented in this paper which suggested an association between the M and H genes, it appeared desirable to summarize all of the data available in respect to linkage relationships between the various genes.

Briggs (2) and Smeltzer (15) reported independence of the M and H genes. However, their data showed a deficiency in the number of susceptible progeny observed in relation to the number expected with a 15:1 ratio. Likewise, an examination of the distribution of F_3 families obtained by them revealed a deficiency of progenies heterozygous for the H gene which would suggest linkage. Four sets of data involving crosses between the M and H genes were available for study. These data are summarized in table 2. In each of the

⁴ Baker, *Ibid.*

Table 2.—The ratios of resistant and heterozygous to susceptible progenies in crosses involving resistance to bunt, and goodness of fit to ratios indicated

Hybrid	Literature citation	No. of F_2 progenies observed		Ratio Res. and Het.: Susceptible	Probability	
		Resistant and heterozygous	Susceptible		15:1 ratio	With recombination value as indicated
MM × HH						(37.24 ± 4.19%)
Calif. 3028 × Sel. 1403	—	155	3	52:1	>0.02	>0.20
Calif. 3029 × Sel. 1403	—	147	4	32:1	>0.05	>0.50
Sel. 1418 × Martin	(2)	78	3	26:1	>0.20	>0.90
Cooperatorka × Sel. 1403	(15)	146	9	16:1	>0.70	>0.10
Total		526	19	28:1	<0.01	
MM × RR						(29.25 ± 3.09%)
Calif. 3028 × Rio	—	257	5	51:1	<0.01	>0.80
Calif. 3029 × Rio	—	237	9	27:1	>0.10	>0.05
Rio × Martin	(16)	249	5	50:1	<0.01	>0.80
Cooperatorka × Rio	(15)	259	3	86:1	<0.01	>0.20
Total		1022	22	46:1	<0.01	
MM × TT						(39.71 ± 2.45%)
Calif. 3028	—	259	21	12:1	>0.30	<0.01
Calif. 3029	—	238	12	20:1	>0.30	>0.30
Martin × Turkey 3055	(5)	183	7	26:1	>0.10	>0.90
Martin × Turkey 1558	(5)	179	4	45:1	>0.03	>0.20
Sherman × Turkey 3055	(7)	136	4	34:1	>0.05	>0.50
Martin × Oro	(7)	101	3	34:1	>0.10	>0.50
Martin × Turkey 1558B	(8)	114	7	29:1	>0.20	>0.70
Martin × Turkey 2578	(8)	116	3	39:1	>0.10	>0.30
Cooperatorka × Turkey 3055	(15)	211	5	42:1	>0.02	>0.20
Total		1534	63	24:1	<0.01	
RR × HH						
Rio × Sel. 1403	(16)	238	12	20:1	>0.30	
HH × TT						
Sel. 1403 × Turkey 3055	(6)	127	11	12:1	>0.50	
F_2 Progenies						
TtRr × ttrr		(Heterozygous)	(Susceptible)		3:1 ratio	(15.18 ± 1.57%)
(Turkey 3055 × Rio) F_1 × White Federation		581	51	12:1	<0.01	>0.50
(Turkey 3055 × Rio) F_1 × Poso		69	7	10:1	<0.01	>0.50
(Turkey 3055 × Rio) F_1 × Big Club		394	28	14:1	<0.01	>0.30
Total		1047	86	12:1	<0.01	

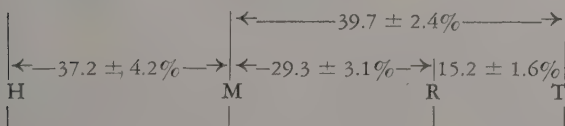
four F_3 populations the ratio of resistant heterozygous to susceptible progenies exceeded the 15:1 ratio expected with independence (table 2). Although the deviation from the expected ratio was significant in only one case, the deviations were all in the same direction and the χ^2 value for the pooled data was highly significant ($P = < 0.01$). When the four populations were tested for homogeneity, according to the method of Snedecor and Brandt, described by Fisher (12) the χ^2 value was nonsignificant ($P = 0.5 - 0.3$). Thus the four sets agree in indicating a deficiency of susceptible progeny for a good fit to the 15:1 ratio expected with independence. The recombination value estimated from the combined data by the method of maximum likelihood was $37.24 \pm 4.19\%$. The P values for the individual crosses are given in table 2.

Four sets of data were available for estimating the cross-over value between the M and R genes. These are given in table 2. The ratio of resistant and segregating to susceptible progenies exceed the 15:1 ratio in all cases. The deviations for 3 of the 4 crosses and for the total were highly significant ($P = < 0.01$). The cross-over value calculated from the combined data was $29.25 \pm 3.09\%$. The nonsignificant χ^2 value for heterogeneity ($P = 0.5 - 0.3$) indicated that the 4 populations agreed in supporting the recombination value obtained.

Briggs (9) in 1940 summarized the results of six crosses involving linkage between the M and T genes. A recombination value of 34.22% was obtained. Three additional sets of data are now available for use in calculating the intensity of this linkage. The data for the nine crosses are summarized in table 2. The ratio of resistant and heterozygous to susceptible progenies exceeded the 15:1 ratio in all but 1 of the 9 populations. In the cross Calif. 3028 $\times$ Turkey 3055 the ratio obtained was less than a 15:1, indicating an excess of susceptible progenies. However, as was pointed out previously in this paper, this discrepancy could be readily accounted for by misclassification.

When the data from the 9 crosses were considered together, there were only 63 susceptible progenies when 100 were expected. This deviation was highly significant ($P = < 0.01$). A recombination value of $39.71 \pm 2.45\%$ was calculated from the combined data. Eight of the nine populations were in good agreement in supporting this value (table 2). The ratio obtained in the cross Calif. 3028 $\times$ Turkey 3055 differed significantly ($P = < 0.01$) from that expected with linkage and accounted for more than two-thirds of the heterogeneity χ^2 value ($\chi^2 = 14.21$, with 8 d.f., $P = 0.10 - 0.05$). The apparent failure to separate accurately the heterozygous and susceptible progenies in this cross would account for the excessive number of susceptible progenies. When this population was omitted from the calculations, a recombination value of $35.85 \pm 2.72\%$ was obtained. Because of the discrepancy noted above, this latter value should be a better estimate of the true relationship between the M and T genes.

Only one set of data was available for each of the crosses involving H $\times$ R and H $\times$ T. Independence of these combinations was indicated (table 2). Thus, the following order of the four genes is suggested:



Baker⁵ found the X gene to be linked with M, R, and T. Since independence was suggested between H and X, it can be assumed that the X gene is located beyond the M gene in respect to the H gene. No additional information is available on this linkage.

Five of the seven genes conditioning resistance to race T-1 of *Tilletia caries* have been shown to be associated in one linkage group. This non-random distribution of the resistance genes between the linkage groups of a species is comparable with the results obtained with powdery mildew of barley (14) and rust of flax (13). Although only three of the five linked genes have been found in a single variety, the amount of crossing-over between them will permit their combination into a single variety with little difficulty.

SUMMARY

Evidence is presented which establishes linkage between the Hussar and Martin genes for bunt resistance, with a recombination value of $37.2 \pm 4.2\%$. Heretofore, the H gene was considered to be independent of the MXRT complex. Thus, five of the seven genes positively identified which condition resistance to race T-1 of *Tilletia caries* are in one linkage group.

All of the data available on the linkage relationships of these genes was summarized. The arrangement of the genes within the linkage group was presented. The recombination value of $15.2 \pm 1.6\%$ between the R and T genes obtained from test crosses involving three susceptible varieties differed significantly from the value of 2.4% previously reported (16).

The resistance of Calif. 3028 and Calif. 3029 was found to be conditioned by the Martin gene. This gene has now been identified in nine varieties.

⁵ *Ibid.*

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Comparison of Actual and Predicted Gains in Barley Selection Experiments¹

K. J. Frey and T. Horner²

SINCE Fisher³ first proposed the idea of partitioning variances, numerous experiments have been conducted by animal and plant breeders to determine the relative importance of environmental and genetic variances in heterogeneous populations. The ratio of genotypic to total variance was termed "heritability" by Lush⁴. It is possible to find in the literature, heritability percentages for various characteristics in most of the important crop plants. However, the literature is notably void of reports testing the realism of heritability values.

The study reported herein was conducted to test the accuracy of heritability percentages for four characters in barley by comparing predicted gains with those actually obtained in selection experiments. The barley plant characteristics measured, namely, yield, test weight, heading date, and plant height, were each considered to be multigenically inherited.

MATERIALS AND METHODS

The data reported herein were collected from barley yield tests grown at East Lansing, Mich., in 1951 and 1952. Fifty-one random lines from the cross, Stewart × Bay, and 39 lines randomly selected from those which were stem rust resistant in the cross, Kindred × Bay, were grown in a yield test in the F_4 generation in 1951 and the F_5 in 1952. Each F_4 and F_5 barley line was composed of the bulk population derived from a single F_2 plant. Each plot was 1 row 8 feet long, and the field design was a randomized block with 4 replications.

Two methods used for calculating heritability were: (1), the regression of the performance of F_5 barley lines on the corresponding F_4 lines, and (2), the ratio of genotypic variance of genotypic plus environmental variances obtained from a components of variance analysis of the F_4 experiment.

The formula used in calculating heritability by this method was:

$$\hat{H} = \frac{\hat{\sigma}_a^2}{\hat{\sigma}_a^2 + \hat{\sigma}_e^2/r}$$

where $\hat{H}$ equaled the estimated heritability, $\hat{\sigma}_a^2$ and $\hat{\sigma}_e^2$ were the estimates of between line variance and environmental variance, respectively, and r is the number of replications. It can be shown,⁵ under the assumptions of normal diploid behavior at meiosis, no multiple alleles, no linkage, no epistasis, and no genotype environmental interactions, that $\hat{\sigma}_a^2$ is equal to the sum of the additive genetic variance plus 1/16 of the dominance variance, while the covariance of mean performance of F_2 lines of the F_4 and F_5 generations is equal to the sum of the additive genetic variance plus 1/32 of the dominance variance. This dominance causes

$$H = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_e^2/r}$$

to have a slight upward bias.

For each characteristic studied, between 10% and 12% of the F_4 population representing the most superior lines in each barley cross were hypothetically selected as parental stock to propagate the F_5 . The predicted mean performance (predicted gain) of the F_5 progenies derived from selected F_4 lines was obtained by multiplying the performance differential between the F_4 population and parental sample means by the heritability percentage. The predicted gain was then compared with the actual mean performance differential between the progeny of the selected parents and the F_5 population mean. If the calculated heritability percentages were reliable and realistic, the predicted and actual gains in performance would approximate one another. This method of comparison was used on each measured characteristic in both crosses except for yield in the Kindred × Bay cross. Since the magnitude of yield, test weight, and plant height were not at the same level for the 2 years, it was necessary to express the expected and actual gain as a percentage of the F_4 and F_5 population means, respectively.

RESULTS

The heritability percentages for yield, test weight, heading date, and plant height in the two barley crosses as calculated by the parent-progeny regression and variance components methods are presented in table 1. Heading date was the only characteristic which showed good agreement between the two methods of calculating heritability. For yield in the Stewart × Bay cross, bushel weight in the Kindred × Bay cross, and plant height in both crosses, the estimate of herit-

¹ Journal Paper No. J-2640 of the Iowa Agr. Exp. Sta., Ames, Iowa. Project No. 1177. Rec. for publication Nov. 17, 1954. Joint contribution from the departments of Agronomy and Statistics.

² Associate Professor of Farm Crops and Assistant Professor of Statistics, respectively.

³ Fisher, R. A. The correlation between relatives on the supposition of Mendelian inheritance. Trans. Roy. Soc. of Edinburgh. 52:399-433. 1918.

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Table 1.—Heritability percentages for yield, test weight, date of heading, and plant height in two barley crosses calculated by parent-progeny regression and components of variance methods.

Characteristic	Cross	Method of calculation	
		Regression	Components of variance
Yield	Stewart × Bay	39	59
Test weight	Stewart × Bay	96	78
	Kindred × Bay	53	60
Plant height	Stewart × Bay	42	75
	Kindred × Bay	50	68
Date of heading	Stewart × Bay	93	94
	Kindred × Bay	85	83

ability by the regression method was lower than by the components of variance method, and for the test weight in the Stewart × Bay cross the converse was true.

The heritability percentages given in table 1 follow the general pattern of those obtained in other studies, namely, date of heading has a high heritability while test weight, yield and height are more easily influenced by environment and, therefore, have lower heritabilities.

It is noteworthy that the heritability percentages calculated by the components of variance method were larger in each case in the Stewart × Bay cross than their counterparts in the Kindred × Bay cross. This was probably caused by the fact that the range for each characteristic was greater in the first cross than in the latter.

The actual versus predicted gains obtained with selection are given in tables 2, 3, 4, and 5 for yield, test weight, plant height, and heading date, respectively. The heritability percentages used in preparing these tables were obtained from the components of variance column in table 1. The selected parental sample in the F_4 of the Stewart × Bay cross yielded 13.0% higher than the population mean, while mean yield of their progenies was 12.1% of the F_5 population mean showing close agreement between the predicted and actual gains in yield through selection. There was good agreement between the expected and actual gains for test weight in the Kindred × Bay cross being 2.0 and 1.7%, respectively, of the population means. In the Stewart × Bay cross the discrepancy between expected and actual gains in bushel weight was quite large being 3.9 and 6.7%, respectively, of the mean.

For plant height, actual gains when expressed as percentage of the population mean fit the expected gains very well in both crosses. In fact, in the Kindred × Bay cross they were almost identical, 4.8 and 4.9% for actual and expected gains, respectively, while in the Stewart × Bay cross they were 8.4 and 7.6%, respectively. The expected gain in heading date in the Kindred × Bay cross was almost identical to that actually obtained. However, in the Stewart × Bay cross the selected sample progenies averaged only 2.9 days earlier than the population mean, while it was expected that they would be 3.4 days earlier. When taller or later parental samples were selected from the F_4 populations the actual gain obtained in their progenies agreed as closely to the gain predicted as the examples shown in tables 4 and 5, so the selection of the earliest and shortest strains as parents herein does not bias the results.

Table 2.—Predicted vs. actual gain in yield by selection in the Stewart × Bay barley cross.

Item	Generation	
	F_4 (1951) gms.	F_5 (1952) gms.
Population mean	88.5	118.9
Selected sample mean*	108.0	133.3
Difference (D)	19.5	14.4
Predicted gain ($H \times D$)	11.5	—
Actual gain	—	14.4
Gain as % of population mean	13.0	12.1

* 5 high yielding lines selected.

Table 3.—Predicted vs. actual gain in test weight with selection in two barley crosses.

Item	Cross			
	Stewart × Bay		Kindred × Bay	
	F_4 (gms./ 25cc.)	F_5 (gms./ 25cc.)	F_4 (gms./ 25cc.)	F_5 (gms./ 25cc.)
Population mean	33.8	29.7	34.3	30.4
Selected sample mean	35.5*	31.7	35.5†	30.9
Difference (D)	1.7	2.0	1.2	0.5
Predicted gain ($H \times D$)	1.3	—	0.7	—
Actual gain	—	2.0	—	0.5
Gain as % of population mean	3.9	6.7	2.0	1.7

* 7 high bushel weight lines selected.

† 6 high bushel weight lines selected.

Table 4.—Predicted vs. actual gain in plant height with selection in two barley crosses.

Item	Cross			
	Stewart × Bay		Kindred × Bay	
	F_4 (ins.)	F_5 (ins.)	F_4 (ins.)	F_5 (ins.)
Population mean	29.8	26.3	32.9	29.1
Selected sample mean	26.5*	24.3	30.6†	27.7
Difference (D)	3.3	2.0	2.3	1.4
Predicted gain ($H \times D$)	2.5	—	1.6	—
Actual gain	—	2.0	—	1.4
Gain as % of population mean	8.4	7.6	4.9	4.8

* 4 shortest lines selected.

† 5 shortest lines selected.

The usefulness of heritability percentages depends upon their reliability which in turn can be proved only in practice. Probably plant breeders will agree that in practice selected phenotypic gain is more nearly maintained in characteristics with high heritability percentages than those with low. However, the data reported herein for barley are even more encouraging because not only do the between-character comparisons fall into line with expectation from experience, but the within-character gains obtained by selection are very close to those predicted. The only extremely divergent case

was for test weight in the Stewart $\times$ Bay cross where the actual gain was nearly twice that expected.

DISCUSSION

The three most common methods for calculating heritability percentages are parent-progeny regressions and two variance components procedures, one where the environmental variance is estimated from error deviations in a replicated trial, and the other where the variance within an isogenic line is considered to be an estimate of environmental variance. The latter variance components method usually used to measure heritability in the F_2 of a segregating cross leads to estimates in the broad sense.⁹ However, the other two procedures give estimates of heritability in the narrow sense. In other words they tend to be based largely on the additive genetic effects which are truly heritable. Therefore, it would be expected that heritability percentages calculated from the same data by these two methods should be quite similar. Any discrepancy between the two methods should be as noted earlier in a higher estimation by the components of variance method due to the greater effect of dominance. The upward bias in the F_4 and F_5 should be only slight. This postulated upward bias might account for the fact (tables 2 to 5) that except for test weight in the Stewart $\times$ Bay cross and heading date in the Kindred $\times$ Bay cross, the expected gains were slightly but consistently greater than those actually obtained.

As pointed out earlier, there was close agreement between the two methods in only two of the seven comparisons. In both crosses there was good agreement for date of heading, while in four of the five other cases, namely, yield in the Stewart $\times$ Bay cross, test weight in the Kindred $\times$ Bay cross, and plant height in both crosses, the regression method gave lower heritability percentages than the variance components method. These differences were too great in magnitude to be accounted for by dominance effects, especially since the variance components method was more accurate in these four cases as evidenced by the fact that the actual gain obtained coincided more closely with those predicted by this method than those predicted by the regression method. Only for test weight in the Stewart $\times$ Bay cross was the converse true, and in this case neither method gave a very close approximation between expected and actual gains.

The most realistic method of calculating heritabilities would seem to be by parent-offspring regression since it more nearly represents what plant breeders practice when selecting within segregating populations. It incorporates genotype-environment interactions which are inherent with practice but are not so prominent in heritability percentages calculated from one set of environmental conditions.

Heritability percentages calculated by the components of variance method are usually based on data from one generation and year and then are applied to the next generation. Under such circumstances, a great deal of discrepancy would be expected between the gain obtained in the F_5 and that predicted on the basis of the F_4 because of genotype-year interaction. However, contrary to this theory the components of variance method overall gave heritability percentages which most closely fit the results obtained in these selection experiments. Apparently, the regression method tended to underestimate the true heritability percentages. Of course, an

Table 5.—Predicted vs. actual gain in heading date with selection in two barley crosses.

Item	Cross			
	Stewart $\times$ Bay		Kindred $\times$ Bay	
	F_4 (days)	F_5 (days)	F_4 (days)	F_5 (days)
Population mean.....	10.5*	8.4	12.2	10.2
Selected sample mean..	6.8†	5.5	8.5‡	7.0
Difference (D).....	3.7	2.9	3.7	3.2
Predicted gain ($H \times D$)	3.4	—	3.1	—
Actual gain.....	—	2.9	—	3.2

* Days after June 12.

† 6 earliest lines selected.

‡ 5 earliest lines selected.

underestimation of heritability percentage would not be as serious as an overestimation since the actual gain obtained would be greater than that expected.

It is generally accepted that segregating populations with the widest ranges tend to give the highest heritability percentages. Such was the case herein where the heritability percentages from the Stewart $\times$ Bay cross were greater than their counterparts in the Kindred $\times$ Bay cross. This suggests the need for adjusting the heritability percentage used in calculating expected gain in performance through selection to the range of the segregating population being subjected to selection. A possible method of alleviating the effect of range on heritability percentage would be to base heritability and selection in terms of standard deviation units. This would bring all frequency distributions of performance more or less to a common base.

Insofar as the data reported herein are representative, they show the following: (a) heritability values as calculated by the components of variance method, in the F_4 and F_5 generations, are realistic and reliable; (b) the close agreement between the expected and actual gains in performance in six of the seven comparisons suggest that the gene action involved in the F_4 and F_5 generations is largely additive; (c) of the two methods of calculating heritability percentages, namely parent-progeny regression and components of variance, the latter gives closer agreement between predicted and actual gains in selection experiments; (d) the parent-progeny regression method tends to underestimate the true heritability percentages.

SUMMARY

In a comparison between two methods of calculating heritability percentages using performance data from the F_4 and F_5 of two barley crosses, the parent-progeny regression method tended to underestimate the true heritability percentages while the components of variance method gave values which closely approximated the results obtained in selection experiments. Only for date of heading was there close agreement between the heritability percentages calculated by the two methods. Other characteristics measured were yield, test weight, and plant height.

When the actual gains obtained through selection and those expected from the components of variance analysis were expressed as a percent of the population mean, the agreement was nearly perfect in all cases except test weight in the Stewart $\times$ Bay cross. In this case, the gain obtained was nearly twice as great as expected.

⁹ Lush, J. L. Heritability of quantitative characters in farm animals. Proc. Eighth Int. Cong. Gen. 1948. Hereditas Suppl. Vol.: 356-375. 1949.

Expression of the "Kys" Type of Male Sterility in Strains of Corn With Normal Cytoplasm¹

Earl R. Leng and L. F. Bauman²

CYTOPLASMIC male sterility has been successfully and extensively used during the past several years to reduce the amount of detasseling necessary in the production of commercial hybrid corn. However, the sterility produced by the widely-used cytoplasmic factors described by Jones (2), Jones and Mangelsdorf (3), and Rogers and Edwardson (5) normally persists into the double-cross hybrid grown in the farmer's field. Complete elimination of detasseling by the use of these sources of male sterility will not be possible until dependable fertility-restoring factors can be incorporated into inbred lines used on the pollinator side of the pedigree in commercial seed production.

As pointed out by Bauman (1) and Jugenheimer (4), the "Kys" type of male sterility, first described by Schwartz (6), appeared to offer the great advantage that fertility in the commercial double-cross hybrid could be restored automatically by using normal, standard inbred lines or their single-cross hybrids as pollinators in making up the hybrid. Breeding plans were developed (1) to introduce this source of sterility into several inbred lines commonly used on the seed parent side of commercial hybrids, and the source material was widely distributed to station and commercial corn breeders for incorporation into their own material.

Successful utilization of the "Kys" type of sterility was dependent on the assumed presence of both cytoplasmic and genetic factors controlling the expression of sterility or fertility. Schwartz (6) had postulated that sterility would result only when the proper genetic factors were combined with a specific "sterile" cytoplasm. Results obtained by the authors in the 1954-55 Florida winter nursery crop clearly indicate either that the postulated "sterile" cytoplasm exists in all three of the standard inbred lines tested, or else that no cytoplasmic factor is involved. In either case, it appears on present evidence that this source of sterility *cannot* be used to produce a fully sterile plant population.

It is the purpose of this paper to give a brief outline of the breeding procedures employed and the results obtained, as well as to present the evidence for the absence of a "fertile" cytoplasm in the inbred lines studied. It is also the desire of the authors to emphasize that, on the basis of present knowledge, this source of sterility cannot be employed successfully in the production of commercial corn hybrids.

GENETIC THEORY AND BREEDING PROGRAM

Schwartz (6) described the occurrence of the "Kys" type of male sterility as resulting from the interaction of a specific "sterile" cytoplasm with two pairs of genetic factors.

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According to this explanation, sterility would occur only in plants which carried the "sterile" cytoplasm, were at least heterozygous for the dominant male-sterility gene $M_{S_{21}}$, and were homozygous for the recessive "suppressor" gene $s^{ga}s^{ga}$. On this basis, all alternative conditions either of the cytoplasm or of the genetic factors would produce complete fertility (table 1).

Extensive tests conducted by the junior author (1) indicated that all of 250 inbred lines tested were homozygous for the dominant suppressor allele $S^{ga}S^{ga}$. Breeding tests with four standard inbred lines indicated that they carried the homozygous dominant factors $M_{S_{21}}M_{S_{21}}$, and it was considered that inbred Kys probably was unique in carrying the recessive alleles of both genes. Tests of the cytoplasmic constitution of the standard lines were not conducted, since such tests would have required several plant generations, and since there was no apparent reason to question the existence of a specific "sterile" cytoplasm, as postulated by Schwartz.

Essentially, the complex breeding procedure finally developed (table 2) involved the identification of double recessive individuals, carrying the "sterile" cytoplasm, with progressively higher proportions of the recurrent inbred germ plasm. These were then used as female parents in backcrosses to the recurrent line, to retain the "sterile" cytoplasm, and the resulting progeny were again crossed to the recovered $m_{S_{21}}m_{S_{21}}s^{ga}s^{ga}$ stock. Finally, when "sterile cytoplasm, double

Table 1.—Expression of the "Kys" type of male sterility in corn, as influenced by cytoplasm and genotype, according to hypothesis of Schwartz (6).

Assumed cytoplasmic condition	Genotype*	Abbreviated symbols†	Phenotype
"Sterile"	$M_{S_{21}}M_{S_{21}}s^{ga}s^{ga}$	□ $MsMs ss$	Sterile
"Fertile"	$M_{S_{21}}M_{S_{21}}S^{ga}S^{ga}$	O $MsMs ss$	Fertile
"Sterile"	$m_{S_{21}}m_{S_{21}}s^{ga}s^{ga}$	□ $msms ss$	Fertile
"Sterile"	$M_{S_{21}}m_{S_{21}}S^{ga}S^{ga}$	□ $MsMs SS$	Fertile
"Sterile"	$m_{S_{21}}m_{S_{21}}S^{ga}S^{ga}$	□ $msms SS$	Fertile
"Fertile"	any other	O - - -	Fertile

* Heterozygous condition, $M_{S_{21}}m_{S_{21}}$, would produce same phenotype as homozygous dominant.

† □ = "sterile" cytoplasm $M_S = M_{S_{21}}$ $S = S^{ga}$
O = "fertile" cytoplasm $m_s = m_{S_{21}}$ $s = s^{ga}$

Table 2.—Planned breeding procedure for incorporation of "Kys" type of male sterility into inbred lines of corn.

Generation	Female parent	×	Male parent
1	□ $msms ss$ (Kys M.S.)	×	O $MsMs SS$ (WF9)
2	□ $Msms Ss$	×	□ $msms ss$ (Kys M.S.)
3	□ $msms ss$ (25% WF9) (selected segregate)	×	O $MsMs SS$ (WF9)
4	□ $Msms Ss$ (62.5% WF9)	×	□ $msms ss$ (25% WF9)

(Repeat cycles until approximately 95% increment of inbred germ plasm reached)

Table 3.—Proposed utilization of the "Kys" type of male sterility in the production of commercial hybrid corn.*

Generation	Female parent	Male parent
Foundation single cross	$\square$ <i>msms ss</i> (fertile) recovered WF9	$\times$ <i>O MsMs ss</i> (fertile) recovered 38-11
Double-cross production	$\square$ <i>Msms ss</i> (male sterile) recovered WF9 $\times$ rec. 38-11	$\times$ <i>O MsMs SS</i> (fertile) normal Hy $\times$ L317
Farmer's crop	$\square$ <i>MsMs SS</i> $\square$ <i>Msms SS</i> $\square$ <i>MsMs Ss</i> $\square$ <i>Msms Ss</i>	} (all fertile) recovered U. S. 13

* Dependent on the presence of specific "sterile" and "fertile" cytoplasm, as indicated.

Table 4.—Segregation of male sterile and fertile plants in progenies with assumed "sterile" and "fertile" cytoplasm. Data from observations at Homestead, Florida, February, 1955.

Recurrent inbred line	"Sterile cytoplasm" crosses ($\square$ <i>Msms Ss</i> $\times$ <i>msms ss</i>)			"Fertile cytoplasm" crosses (<i>O Msms Ss</i> $\times$ $\square$ <i>msms ss</i>)		
	Number of families	Sterile plants	Fertile plants	Number of families	Sterile plants	Fertile plants
38-11	8	78	199	6	52	141
WF9	2	23	47	3	28	70
Hy2	5	36	108	6	49	144
Totals	15	137	354	15	129	355

recessive" stocks with a sufficiently high proportion of the recurrent line's germ plasma had been produced, they were to be used to produce a "fertile cytoplasm, $M_{21}M_{21} s^{ga,ga}$ " type³. According to Schwartz' hypothesis, such types should have been *genotypically* male sterile, but *phenotypically* male fertile, because of the presence of the "fertile" cytoplasm. Fully male-sterile single cross hybrids were then to be produced from two male fertile recovered lines by the procedure outlined in table 3.

CRITICAL TESTS AND RESULTS

After several generations of experimental breeding, employing the four widely-used standard inbred lines WF9, 38-11, Hy2, and M14, the first cross of the type

$$O MsMs SS \times \square msms ss^4$$

(normal inbred 38-11) (tester)

was made by the junior author in 1953. The backcross to the tester

$$O Msms Ss \times \square msms ss$$

was made in the 1953-54 Florida winter nursery, and the resulting segregating population was grown by the senior author in 1954. Severe drought prevented pollen shedding in most of the plants, and no satisfactory observations were made.

Additional crosses of this type, involving the three normal inbreds WF9, 38-11, and Hy2 and various recovered $\square$ *msms ss* stocks, were made in the 1953-54 Florida nursery. The backcrosses to the respective $\square$ *msms ss* stocks were made at Urbana in 1954. When the resulting segregating progenies were grown in the 1954-55 Florida winter nur-

ery, it was found (table 4) that they were segregating for male sterility in exactly the manner which would have been expected had they been carrying "sterile" cytoplasm.

Comparison of the ratios of sterile to fertile plants in these progenies, carrying the presumed "fertile" cytoplasm, with those of similar progenies carrying "sterile" cytoplasm showed (table 4) that the two sets of ratios were virtually identical. It was therefore concluded that inbreds WF9, 38-11, and Hy2 were carrying a "sterile" cytoplasm also, or else that no specific "sterile" cytoplasm actually was necessary for the expression of the "Kys" type of male sterility.

DISCUSSION

The feasibility of using the "Kys" type of male sterility in commercial seed production was dependent on the development and use of a cytoplasmically *fertile*, *genotypically sterile* recovered inbred line, which would actually be male fertile. Therefore, it is obvious that this system cannot be used with inbred lines which do not carry a "fertile" cytoplasm. The three lines tested in the studies reported here all proved to carry a "sterile" cytoplasm, or its equivalent. Obviously, then, this source of male sterility cannot be used successfully with these lines. Further, these findings raise considerable doubt that any specific "sterile" cytoplasm actually is necessary for the expression of male sterility in plants of the "sterile" genotype $M_{21}m_{21} s^{ga,ga}$.

It is not the purpose of this paper to give a detailed analysis of this and other anomalies in the obviously complex inheritance of the "Kys" type of male sterility in corn. Although extensive data are available, further test crosses and counts of segregating populations will be required to clarify the situation. On the basis of present evidence, however, the authors emphasize that there appears to be no justification for further attempts to incorporate this source of sterility into inbred lines for use in commercial production.

³ Bauman, L. F. Results of further inheritance studies on the Kys type of cytoplasmic male sterility in corn. Paper presented at the 1953 meetings of the American Society of Agronomy, Dallas, Tex., November 16-20, 1953.

⁴ Refer to table 1 for key to abbreviated notation.

SUMMARY

The "Kys" type of male sterility in corn has been described as resulting from the interaction of a specific "sterile" cytoplasm with two pairs of genetic factors, namely, a dominant male sterility gene, M_{s21} , and a recessive suppressor gene pair, s^{ga}, s^{ga} . This type of male sterility appeared to offer definite advantages over other types now being used to eliminate detasseling in the production of hybrid seed corn, and a breeding program was begun at the Illinois Station to incorporate the assumed "sterile" cytoplasm and the necessary genetic factors into four widely-used standard inbred lines.

Successful utilization of the "Kys" type of sterility depended on the ultimate production of one or more recovered lines which would be *genotypically* sterile, but *phenotypically* fertile, because of the presence of "fertile" cytoplasm. Attempts to produce such stocks revealed that all three inbred lines tested carried a "sterile", rather than a "fertile" cytoplasm; in fact, the data obtained raised the definite possibility that no special condition of the cytoplasm is necessary for the production of the "Kys" type of sterility.

These results indicate that this type of male sterility cannot be employed successfully to produce fully male-sterile single crosses, for use in hybrid seed corn production. It is therefore recommended that efforts to incorporate the "Kys" type of sterility into inbred lines for such use be discontinued.

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Pros and Cons of Changing Fertilizer Guarantees from the Oxide to the Elemental Basis^{1 2}

THE fertilizer industry throughout the world is undergoing a tremendous expansion and more changes in technology than ever before in its history. It has long ago ceased to be a by-products or waste-products business and has become a major segment of the heavy chemical industry.

For at least 30 years there has been some agitation to discontinue the practice of expressing the phosphorus and potassium contents of fertilizers in terms of the oxides. However, it appears that little effort has been made to describe the history of this practice or to record the pertinent discussions concerning the advisability of making a change. The problem has received more attention in some of the European countries than in the United States.

The current discussion in this country originated with a resolution which was passed by the Middle West agronomists at a joint agronomy-industry meeting sponsored by the Middle West Soil Improvement Committee, Feb. 16, 1951. The resolution read as follows:

"This resolution is directed to a number of organizations, including the following:

Middle West Soil Improvement Committee
National Fertilizer Association
American Plant Food Council
Southern Agricultural Workers Association
Association of Official Agricultural Chemists
Fertilizer Division of the American Chemical Society
National Soil & Fertilizer Research Committee
The American Horticultural Society
American Society of Agronomy, and
Soil Science Society of America

"Agronomists of the North Central Region, at the time of their annual meeting on Feb. 15, 1951, to consider fertilizer grades, ratios, and other matters pertaining to fertilizer usage, recom-

mended to the above-named group that consideration be given to the matter of expressing the contents of nutrient elements in fertilizer, including the minor elements, on an elemental basis. It is hoped that the appropriate committees and/or organizations as such will discuss this matter at their next annual meetings and make such recommendations as they may deem desirable through the Secretary of the Association of Official Agricultural Chemists."

Then, the American Association of Fertilizer Control Officials in October 1952, passed the following resolution:

"Moved that the Uniform Fertilizer Bill be modified to change the designations 'phosphoric acid' to 'phosphorus' and 'potash' to 'potassium', provided, however, that permissive guarantees for P_2O_5 and K_2O may be included until such time as essentially complete conversion to the elemental basis can be effected.

"Moved further that a committee of Association of Fertilizer Control Officials be appointed to meet with representatives of the National Soil and Fertilizer Research Committee, and with committees of the Soil Science Society of America, American Plant Food Council, and National Fertilizer Association to prepare a plan for changing the method of expressing fertilizer guarantees from phosphoric acid to phosphorus, potash to potassium, and available phosphorus to soluble phosphorus."

Also, in 1952, a Sub-committee of the Fertilizer Committee of the Soil Science Society of America was appointed on "Consideration of the Advisability of Changing Fertilizer Guarantees to Elemental Basis."

This committee met with the AAFCO committee and with representatives of the fertilizer industry in Washington, D. C. in October 1953, to explore the possibilities of getting an objective analysis of the problem. It was agreed that the history of the use of these terms should be recorded and the arguments for and against a change to the elemental basis should be fully publicized as a basis for determining whether concerted action by the interested groups would be advisable.

The following statement sets forth the history of the use of these terms and the arguments which have been advanced for and against the expression of plant nutrient content of fertilizers in terms of the elements.

Historical

The use of the oxide form for reporting the composition of fertilizers, plants, and soils appears to be a carryover from rock

¹Prepared by a Sub-committee of the Fertilizer Committee of the Soil Science Society of America on "Consideration of the Advisability of Changing Fertilizer Guarantees to the Elemental Basis". The Fertilizer Committee voted unanimously at a meeting in St. Paul, Minn., Nov. 9, 1954, to recommend that all fertilizer guarantees be expressed in terms of the element. The Executive Committee of the Soil Science Society of America approved the report of the Fertilizer Committee.

²This report may be reprinted or reproduced, in whole or in part, without permission.

analysis. In the latter case the oxide mode was used to show the known valences of the elements in the sample and with suitable corrections would total 100% for a complete analysis. It is difficult to determine with accuracy the exact origin of the practice of expressing the mineral content of fertilizers in the form of oxides.

Crowther (2) stated "The persistence of the old terms [P_2O_5 and K_2O] is partly due to the mistaken idea that there is something remotely academic in talking about chemical elements, partly to the desire to make analyses look bigger, but mainly to the traditional survival in agricultural and industrial chemistry of the nomenclature of a century ago." In discussing the origin of the term, P_2O_5 , Smith (9) noted "Nomenclature in the textbooks of a century ago was inclined to be irregular, some authors using the terms phosphorus pentoxide or phosphoric anhydride for P_2O_5 and phosphoric acid for H_3PO_4 , while others used phosphoric acid for both P_2O_5 and H_3PO_4 and sometimes hydrate of phosphoric acid for H_3PO_4 . It should be remembered that the oxygen theory of acids was still prevalent about 100 years ago. In the course of time, however, the practice of calling P_2O_5 phosphoric acid seems to have become universal and agricultural chemists have rather shamefully accepted or condoned the custom."

At the Second National Fertilizer Conference held in West Baden, Ind., in 1928 the question of changing from P_2O_5 to P and from K_2O to K as a basis for expressing the phosphorus and potassium content of fertilizers was presented. The conference proceedings (7) recorded the discussion which indicated that the participants believed that there was no sound basis for using the oxide form other than the fact that state laws required it.

Sauchelli (8) in 1948 reported on a survey of the fertilizer industry on the question "N-P-K or N- P_2O_5 - K_2O ?" Mixed reactions to the proposal were obtained. He concluded that the use of P_2O_5 and K_2O to show the phosphorus and potassium contents of fertilizers was "a holdover from the old oxide theory which was discredited long ago." Likewise, Crowther (3) attributed the use of the oxide form to the abandoned theory that salts are compounds of "acid oxides" and "basic oxides." More recently Jacob (4) quoted a report from Denmark as follows, "It has been disappointing that the large countries still use P_2O_5 and K_2O . There is no scientific reason to do so. Why not, to be consistent, use N_2O_5 instead of N? Ammonium nitrate will then turn out to be a very concentrated fertilizer, containing more than 100 percent N_2O_5 ." Others have suggested that N_2O_5 would be the proper oxide form for anionic nitrogen but not for cationic nitrogen.

Sauchelli (8) pointed out that nitrogen in fertilizer was formerly expressed as ammonia, NH_3 , and that the chemist using the Kjeldahl method for determining nitrogen was actually distilling NH_3 and reporting it as such. Brand (1), former executive secretary-treasurer of the National Fertilizer Association, recognized the fallacy of using the NH_3 form to express the nitrogen content of fertilizers inasmuch as some carriers do not contain ammoniacal nitrogen. In spite of all the arguments advanced against the practice of expressing nitrogen as ammonia, only since 1950 have the guarantees of nitrogen in fertilizer been expressed in terms of the element (N) in all the states and territories. South Carolina was the last state to make the change from NH_3 to N—Aug. 1, 1939—and complete uniformity was achieved when the change was made in Puerto Rico, Jan. 1, 1951.

Confusion of Terminology

The literature contains many confusing statements as a result of failure to adopt a uniform method of expressing the nutrient content of fertilizers, soils, and plants. The lack of consistency among writers is well known. Often, a particular writer is inconsistent, even within a sentence or paragraph. The following quotations, extracted from soils and fertilizer publications illustrate the difficulties encountered due to present terminology (italics by the authors of this report are for emphasis).

1. "A release rate for *phosphoric acid* ranging from 8 lbs. to 29 lbs. per acre per year was found at 11 different locations in a recent . . . study of *phosphorus* availability."
2. "The *phosphorus* content of the surface foot of soil varies considerably. . . . It ranges up to the equivalent of about 0.3 per cent P_2O_5 . . ."
3. "In the phosphate rock industry, the P_2O_5 content is usually expressed in terms of its *tricalcium phosphate*, $Ca_3(PO_4)_2$, equivalent . . ."

4. "The custom in the fertilizer trade is to express the *phosphorus* content of any type of phosphatic material as the *anhydride of phosphoric acid*, P_2O_5 . This term is commonly abbreviated, though somewhat confusingly, to '*phosphoric acid*'."
5. "Domestic rock used in superphosphate manufacture runs 68 to 78 per cent B.P.L. (*bone phosphate of lime*) or 31 to 36 per cent of P_2O_5 ."
6. "Mono-calcium phosphate is synthesized by applying *phosphoric acid* to high grade phosphate rock. It contains approximately 50 per cent available *phosphoric acid*."
7. "Since the term '*potash*' covers all natural *potassium* compounds, prices are based on the hypothetical K_2O content of the material involved."
8. "Fertilizers supply more SO_3 and nearly as much CaO as all three of the *primary nutrients*."
9. "Since nitrogen percentage is based on the elemental content whereas *phosphate* and *potash* are reported as the oxides, it can be shown that elemental fertilizer nitrogen is actually lower in cost per pound than either of its companions, *phosphorus* and *potassium*."

Objections to the Change

1. *Historical use* of the oxide form would necessitate an intensive educational effort to acquaint the farmer, industry, control officials, and agricultural workers with the new basis. A change to the elemental basis would require the use of conversion factors to data heretofore published in terms of the oxides. This would, no doubt, lead to some confusion and to additional calculations until the new system is generally accepted. For instance, the following conversion factors would need widespread publicity:

From	To	Factor
P_2O_5 -----	P	0.44
P -----	P_2O_5	2.29
K_2O -----	K	0.83
K -----	K_2O	1.20

The change in ratio and grade numbers will present a "mind block", at first thought, to those accustomed to use the N- P_2O_5 - K_2O system. For example, a 1:1:1 ratio will become a 7:3:6 ratio. However, such grades could be standardized readily to fit a 2:1:2 ratio on the N:P:K basis.

2. *Fertilizer laws* would need revision on a coordinated national basis. Legislative action probably would be required in many states to permit the change. In this case it would take a period of several years to accomplish the transition. It is generally agreed that during the transition period, the laws or regulations governing the sale of fertilizers should permit—and perhaps require—the phosphorus and potassium contents to be shown in terms of the oxides as well as in terms of P and K. Since the objective would be to drop eventually the oxide terms, these values should be carried as supplementary statistics in small print during the period of transition.

For the change to be made with a minimum of confusion and without penalties to those members of industry who are willing to pioneer in the field, nearly unanimous backing of all groups would be needed.

Jacob (4) noted that no particular trouble was encountered in Norway in making the change from P_2O_5 and K_2O to P and K. It is recognized, however, that a similar change in the United States would involve more complications since most of the fertilizers are sold and applied in European countries as separate materials and not as mixtures.

3. *An impression of lowering the "plant food" content* of fertilizers would be created in the minds of those without an elementary knowledge of chemistry. Since 1 part of P_2O_5 is equivalent to only 0.44 parts of P and 1 part of K_2O to 0.83 parts K, this would give to some people the impression of less "plant food" per dollar invested. By the same process, they would conclude that there was more filler in the fertilizer bag.

On the other hand, the task of educating those who are receptive would be greatly simplified. It would appear much easier to explain why superphosphate contains 8.8% phosphorus which has the symbol P than it would explain why the phosphorus content of superphosphate is shown as 20% P_2O_5 which is called

"phosphoric acid" but isn't phosphoric acid at all but is in reality phosphorus pentoxide.

4. *Costs* incidental to the change would be passed on to the farmer. Although the costs of making the change would be temporary, and ultimately savings inherent in the new system should offset them, the task of acquainting industrial personnel with the new system, mistakes which inevitably will be made in the calculation of formulas, and new plates for printing of bags and tags are items of expense which will be encountered.

5. *Whole number concepts* for N, P, and K would no doubt be retained, and as a result the change would require a complete revision of formulas for fertilizer mixtures. Until new whole number ratios could be established, decimal numbers in guarantees might be necessary in some cases while the transition is being completed in all states.

Fractions would still be involved in expressing the percentages of the minor elements in fertilizers.

Advantages of the N-P-K System

1. *Uniformity* of terminology in expressing the plant nutrient content of soils, plant materials, and fertilizers would greatly lessen the confusion in both written and spoken word. The composition of plant materials is generally expressed in present-day literature in terms of the element. This method of expression for the mineral elements is already firmly established in the animal nutrition and biochemical fields. Feeding standards for such elements as phosphorus and calcium are usually expressed in terms of the element and then converted to show the amount of a standard source material to use to supply the required level of the element in question. Likewise, soil tests are frequently calibrated on an elemental basis. A common basis for expressing the plant nutrient content of these materials would make the interpretation of soils and crop data in terms of fertilizer much simpler. Since nitrogen in fertilizers is already expressed in terms of the element, the shift would, first of all, provide for uniformity in fertilizer grade terminology.

The increasing importance of the so-called secondary and minor elements would be an additional argument for using a simple elemental basis for expressing the nutrient content of fertilizers. It is difficult to rationalize the complexity of terminology which is developing in the fertilizer field. Some nutrients are guaranteed in terms of the element, some as oxides, and some as compounds or commercial products. For example, a popular grade of fertilizer in Virginia which is recommended for alfalfa might be guaranteed to contain 2% nitrogen (N), 12% phosphoric acid (P_2O_5), 12% potash (K_2O) and 5% borax equivalent. Actually the boron may not be in the form of borax (sodium tetraborate decahydrate) at all but in the form of Colemanite (calcium borate)—a compound greatly different in solubility. Likewise the phosphorus might not be supplied in the form of orthophosphates but as calcium metaphosphate and the potassium would probably be supplied as the chloride salt of that element.

2. *Simplicity* is another worthy objective of the change. A true nomenclature of plant nutrient elements would not permit the use of such terms as " P_2O_5 or phosphoric acid" and " K_2O or potash." The increasing use of orthophosphoric acid, H_3PO_4 , as a fertilizer material for direct application has added to the confusion when P_2O_5 is referred to as "Phosphoric acid." The AAFCO went on record in 1954 as favoring the abandonment of the term "phosphoric acid" for P_2O_5 , recommending that it be called phosphorus pentoxide. It would be much simpler to express phosphorus as the element, and usually the simplest way is the best way. The expression of the potassium content of potassium chloride, KCl, as an oxide appears less defensible since it has been known since 1810 that there is no oxygen in KCl.

It has been pointed out that the present practice of using P_2O_5 and K_2O to express the content of phosphorus and potassium is irrational since it requires 7 symbols and figures when 2 will serve. The saving in printing, stamping, and typing—the small suffix figures require special attention by typists and printers—would be significant to say nothing of the space saved in explaining the meaning of P_2O_5 and K_2O . It is a common practice to refer to NPK fertilizers and then make calculations in terms of N, P_2O_5 , and K_2O . There is little doubt that the use of such arbitrary terminology has affected materially the types and amounts of fertilizer used and has been a real obstacle in educational programs with the farmer. Progress in any field is hampered by holding to terminology and concepts long after they have been discredited.

3. *Accuracy* in stating the true ratios of the major nutrient elements in a particular fertilizer would require that they be

stated in terms of the element. Expressing the nutrient content of fertilizers in such terms as P_2O_5 , K_2O , CaO , SO_3 , creates erroneous impressions as to the actual amounts of the plant nutrient elements in fertilizer materials. Ratios of the nutrient element contents of a fertilizer are frequently used in referring to "nutrient balance" in relation to fertilizer use. The 1:1:1 ratio denotes a favorable balance of the three elements to many people and the impression is held that because of the widespread use of fertilizers with a 1:2:1 or 1:3:1 ratio (N- P_2O_5 - K_2O basis) large quantities of phosphorus in relation to the other elements are being used. Conversion to the elemental basis shows this to be a misconception, since a 1:2:1 ratio in conventional terms becomes a 1:0.88:0.83 ratio as N-P-K.

The use of the term P_2O_5 has been defended on the basis that it denotes the orthophosphate form of phosphorus in fertilizers. This is untenable since it has been shown by Jacob and Hill (5) that about 41 compounds have been identified in fertilizers and related materials. These include 23 orthophosphates, 7 pyrophosphates, 7 metaphosphates, and 4 polyphosphates.

If the oxide form originated in rock analysis as a method of showing true valence of the element, its present use in fertilizer analyses is erroneous. For example, the phosphorus content of phosphites is expressed as P_2O_5 whereas the correct oxide to show the valence of phosphorus in phosphites would be P_2O_3 .

The oxide is not the basic functional unit either from a physical or chemical standpoint. The atom might be considered the functional unit from the viewpoint of the physicist but the ion would generally be the functional unit from a chemical or crystal structure point of view. Actually chemistry is of little help or importance in this case. The important information in a guarantee is the amount of the constituent and the simplest form of statement is preferable. More complex forms such as the oxide or ions convey no pertinent information. The nutritive value or "availability" of the constituent cannot be shown by the mode of expression.

Summary

Some of the valid objections to changing from the oxide to the elemental basis as a mode of expressing nutrient guarantees of fertilizers include: (1) Historical use of the oxide terms would require an intensive educational effort to acquaint all groups involved with the new system, (2) Fertilizer laws would need revision on a coordinated national scale, (3) Costs incidental to the change and (4) a complete revision of grades and formulas would be required to maintain the whole number system.

The utility of the elemental basis (the N-P-K system) in fertilizer guarantees highlights the true advantages of this system. A uniform method for stating the nutrient composition of fertilizer materials, plants, and feeds would greatly simplify exchange of information in the closely related fields of soil chemistry, fertilizer technology, and plant (and animal) nutrition. Simplicity of the elemental system and the fact that it is a more accurate expression of the plant nutrient content are strong arguments for making the change. The logic is apparent of any change which simplifies, adds consistency or uniformity, increases the accuracy, and greatly improves the usefulness of the system.

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Notes

A PORTABLE SELF-PROPELLED PLOT COMBINE¹

THREE methods of harvesting experimental plots of small grains and seed crops have been generally employed. The method in longest use is that of cutting the plants from definite lengths of rows or numbers of quadrats by hand, bagging or wrapping them to prevent shattering and loss of seed during transportation, and threshing with a small stationary plot thresher or other means. A second method is similar except that cutting is done with a small plot mower, having some type of catcher to collect the plants as they are cut. A third method is that of employing a commercial self-propelled combine to cut and thresh the crop simultaneously.

Each of these methods has disadvantages. The relatively large amount of hand labor involved in the first two methods limits the number of plots that may be handled by an experimenter and encourages reduction in plot and sample size. Combines have the advantage of completing the harvest in a single operation. However, present day commercial self-propelled combines are of such size (7-foot cut, or larger) that the experimental area required for plots to be harvested by them may be so large as to include undesirable site heterogeneity. Relatively large amounts of labor and materials are necessary for application of treatments to plots of the required size. The machines are difficult or impractical to clean between plots of different treatments or varieties. The sample removed from the combine at the end of a plot may be contaminated by significant amounts of seed from previously harvested plots of different treatments, and is usually not suitable as a sample for chemical analyses, baking trials, or determination of other than yield effects of treatments. Because of their weight, bulk, low road speed, and the difficulties involved in transporting them by truck under bridges and overpasses, power lines, telephone lines, and other obstructions along the highways, use of commercial self-propelled combines is usually limited to sites near their permanent location.

A self-propelled plot combine was described in 1951 by Liljedahl, Hancock, and Butler.² Their machine was a significant advance in plot-harvesting equipment for crops that may be combined. An Allis-Chalmers Model G tractor, with front end and rear wheels removed, was mounted above the combine body as source of motive power for the truck wheels upon which the front end of the machine was carried. A 6 hp. air-cooled engine powered the thresher.

Three portable self-propelled plot combines have been constructed and used at the Oregon Agricultural Experiment Station during the 1953 and 1954 seasons. The basic unit of these machines is an Allis-Chalmers Model 40 All-Crop Harvester, stripped of frame, wheels, clean grain elevator, and tailings elevator and streamlined inside essentially as recommended by Liljedahl, Hancock, and Butler.

¹ Approved for publication as Miscellaneous Paper No. 9 by the Director of the Oregon Agr. Exp. Sta. and the Chief of the Soil and Water Conservation Research Branch, A.R.S., U.S.D.A. Contributions of the Department of Soils and the Department of Farm Crops of OAES and of the Western Section of Soil and Water Management of SWCRB. Rec. for publication Dec. 20, 1954.

² A self-propelled plot combine. John B. Liljedahl, N. I. Hancock, and James L. Butler. Agron. Jour. 43:516-517. 1951.

The combine body is placed upon a frame supported at the front by an automobile rear axle and wheels (6.00 x 16 tires) and at the rear by an automobile front axle. Each axle is shortened by 12 inches. A 9 hp. Wisconsin air-cooled engine, mounted low on the left side of the machine, supplies motive power to the automobile rear axle through two automobile transmissions. The arrangement of these components is shown in figure 1. The combine has 6 forward speeds, ranging from about 1 to 7 miles per hour. There are 3 reverse speeds. A 9 hp. Wisconsin engine, mounted low and well forward on the right side of the machine, as shown in figure 2, operates the combine. Low mounting of the engines on opposite sides of the machine results in low over-all height, low center-of-gravity, and good stability. Driver's seat and combine and engine controls are mounted on a platform supported above the machine. A hand-operated hydraulic header lift is provided. Threshed seed is collected beneath the machine in a sliding bin, which has a funnel mouth for ease in transferring to bags. An air compressor may be mounted on the platform and powered from the thresher engine, if it desired to thoroughly clean the machine between varieties.

The complete machine weighs approximately 3,000 pounds. It may easily be driven onto a tilting bed implement trailer under its own power. Loaded thus, it will pass under obstacles

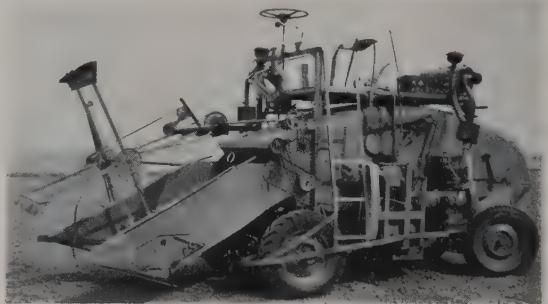


FIG. 1.—Propulsion engine side of combine. The engine and two transmissions are located in front of the rear wheels.

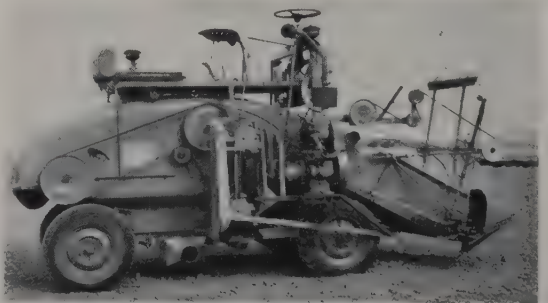


FIG. 2.—Thresher engine side of combine. The engine is located above and back of the front wheel. Threshed grain is collected in the bin which hangs beneath the machine.

higher than about 9½ feet, and may be transplanted behind automobiles or pickup trucks at legal highways speeds.

The combine cuts a swath 40 inches wide. In fertilizer experiments at this station plots are usually made 8 feet wide and 50 feet long; an area 40 inches wide and 40 feet long (133 square feet) is harvested from the central portion of the plots. Where wheat yields 30 bushels per acre this provides a 5½ pound sample. The combine is employed for trimming the plot ends prior to harvesting plot samples.

During the past season, these combines have been used to harvest experimental plots of wheat, barley, beans, alta fescue, and vetch on approximately 80 farms in various portions of Oregon. Two men are sufficient to operate the combine, but it is convenient to have a third man to tie and label the bags containing threshed samples. Crews of 3 men have harvested 30 to 40 plots (50 feet long) per hour. Liljedahl, Hancock, and Butler estimated the combine resulted in 80% saving of manpower in comparison with hand harvesting. With the cleaning mechanism of the combine carefully adjusted to clean the grain, satisfactory weights for yield determinations may be obtained immediately. Where necessary, grain samples may be quickly cleaned of chaff and straw with a Vogel Re-cleaner.³

It is our opinion that portable self-propelled plot combines may be constructed from several other small commercial pull-type combines, but probably none is as compact and light weight as the Allis-Chalmers Model 40. Insofar as we are aware, no implement company is presently manufacturing a commercial combine of a size suitable for conversion into a small portable self-propelled plot combine. Combines of suitable size are only available on the used market. All repair parts are presently available. It is the policy of the larger manufacturers to maintain stocks of repair parts of machines no longer in production for as long as any considerable number of them are in use.

A list of needed materials, drawings, and further description of the Oregon plot combines are available from the authors on request.—ALBERT S. HUNTER and JAMES H. JOHNSON, *Soil Scientist, Oregon Agr. Exp. Sta., and Western Section, Soil and Water Management, SWCRB, ARS, USDA, Corvallis, Oreg., and Farm Foreman, Farm Crops Dept., Oregon Agr. Exp. Sta., Corvallis, Oreg.*

³Designed by Dr. Orval A. Vogel, Agronomist, Agricultural Research Service, Agronomy Department, State College of Washington, Pullman, Wash.

GRASS-LEGUME BAND SEEDING WITH A SHOE TYPE DRILL¹

ESTABLISHMENT of alfalfa, clovers and cool season grasses is often difficult during fall months in southeast Oklahoma. Soil moisture is frequently limiting, with early fall showers usually followed by droughty periods. Low soil fertility is a limiting factor for vigorous seedling growth in most areas. Possibilities of overcoming these hazards to stand establishment include summer fallowing and the seeding of grasses and legumes directly above fertilizer bands in well prepared seedbeds. However, farm equipment now in general use does not offer an efficient means of obtaining precision band seeding with the desired fertilizer placement.

A commercial narrow-furrow, shoe-type drill has proved to be an effective method of accomplishing this band seeding

and fertilizer placement, giving excellent stands of tall fescue, orchard grass, brome, alfalfa, Ladino and common white clover mixtures at the Southeast Oklahoma Pasture Fertility Station, Coalgate, Okla. The seedings were made in 2 experimental pasture areas, totaling about 70 acres. The soil types are principally Dennis silt loam and Verdigris silt loam. These fields were fallowed through the driest summer of record and had good subsoil moisture at 10-inch depth prior to the first fall showers. Two tons of lime per acre were applied broadcast and a smooth, firm seedbed was prepared.

A shoe-type drill was rigged to place high analysis fertilizer in a band at a 2-inch depth, with the grass and legume seed falling at the point where the loose soil flowed together behind the furrow opening drill shoe (figure 1). This gave a good distribution of seed in the upper half inch of soil immediately over the fertilizer band. A wide press wheel following each drill shoe firmed the seedings.

An alfalfa-clover seed mixture was dropped with a uniform seeding rate through the grass seed attachment. The grass seed mixture was applied with excellent precision through the grain box fitted with an agitator. Both grass and legume seed were delivered through a single flexible hose with the opening end held by a clip attached to the rear of the drill shoe. The fertilizer was delivered through a separate flexible hose dropping the fertilizer into the furrow-opening shoe.

An excellent stand of cool season grasses and small seeded legumes was obtained in this manner (figure 2). The use of a narrow-furrow, shoe-type drill offers good possibilities for obtaining precision band seeding for grass and legumes over a deeper placed fertilizer band.



FIG. 1.—A narrow-furrow, shoe-type drill rigged for seeding grass and legume seed directly above a fertilizer band in a prepared seedbed. The small-seeded legume mixture is applied through the grass-seed attachment, and the grass seed is dropped through the grain box fitted with an agitator. Both grass and legume seed are delivered through a single flexible hose dropping the seed at the point where the loose soil flows together behind the drill shoe. The fertilizer is delivered through a separate flexible hose dropping the fertilizer into the furrow opening shoe and placing it in a band at a 2-in. depth. A wide press wheel following each drill shoe firms the seedings.

¹ Rec. for publication Dec. 27, 1954.



FIG. 2.—Cool season grass and perennial legume mixture 6 weeks after seeding directly over a fertilizer band placed at 2-in. depth. Seedlings were established in a well prepared seedbed on land that had been summer fallowed. Two tons of lime were applied per acre, broadcast. The fertilizer applied at seeding was 150 lbs. 10-30-10 per acre. The mixture used was 5 lbs. each tall fescue, brome and orchard grass, 9 lbs. alfalfa and 1 lb. each Ladino and common white clover. The vetch seedlings are volunteer form the previous year's rye-vetch crop.

This type of drill has been used in a similar manner to thicken drouth-thinned established alfalfa stands at the Peanut Experiment Farm, Stratford, Okla. Fall stand establishment in that area has a further hazard from the sharp cutting action of wind-blown sand particles on exposed seedlings during the fall and winter months. The older, scattered plants give protection to young seedlings during that period.—J. Q. LYND, *Oklahoma A. and M. College, Stillwater, Okla.*

LETHALITY IN A WHEAT CROSS¹

LETHAL genetic combinations have been reported in crosses of common wheat varieties,² but they occur so infrequently that they are of little importance in breeding

¹ Rec. for publication Dec. 9, 1954.

² Caldwell, Ralph M., and Compton, L. E. Complementary lethal genes in wheat. *Jour. Heredity* 34:67-70. 1943.

programs. They are, however, of considerable genetic interest. The purpose of this note is to report lethality in a cross of two wheat varieties not previously known to carry lethal factors.

Atlas 66, a soft red winter wheat, was crossed with several soft wheat varieties and with Quanah, a hard red winter variety, in the spring of 1952. Seed of the parent varieties and the hybrid seed were fall planted near Raleigh, N. C. Fall growth appeared normal in all F_1 plants. In February the 20 F_1 plants obtained from the cross Quanah $\times$ Atlas 66 appeared to be dying and by the end of March all plants from this cross were dead. There was a gradual yellowing and weakening of the plants and the leaves died from the tip downward. No pathogenic organism or environmental factor could be associated with this condition. The roots appeared normal.

These two varieties were again hybridized in 1953, but only one seed set. This seed, which was from the reciprocal cross Atlas 66 $\times$ Quanah, was planted with the two parents. The F_1 plant grew normally in the fall, but died in the spring of 1954 as had those in the previous year.

Since Atlas 66 and Quanah, as well as parents and F_1 plants of other crosses grown under the same conditions, were normal, it was concluded that lethal genetic factors were operating in the cross.

These lethal factors appear to be different from those reported by Caldwell and Compton,² who found that seedlings with lethal factors invariably died soon after the four leaf stage. Most of the F_1 plants of the cross reported here reached a height of 8 to 12 inches with several tillers before they died. There is a possibility, however, that the difference in stage of development of the plants at the time of death was due to differences in environmental conditions. The amount of growth was somewhat comparable to the semi-lethal condition described by Sachs³ in some interspecific wheat crosses. He found, however, that an occasional plant in these crosses would produce a single head, whereas none of the plants reported here reached the heading stage.—T. T. HEBERT and G. K. MIDDLETON, *Associate Professor of Plant Pathology and Professor of Agronomy in Small Grain Breeding, respectively, North Carolina Agr. Exp. Sta.*

³ Sachs, Leo. The occurrence of hybrid semi-lethals and the cytology of *Triticum macha* and *Triticum vavilovi*. *Jour. Agr. Sci.* 43:204-213. 1953.

Book Reviews

SMALL FRUIT CULTURE, THIRD EDITION

By James Sheldon Shoemaker. New York, McGraw-Hill Book Co. 447 pp. 1955. \$6.50.

This third edition of Prof. Shoemaker's text is an up-to-date handbook of information on small fruit culture which should be a good reference for individual gardeners as well as for commercial growers. Included are separate sections on grapes, strawberries, brambleberries, currants, gooseberries, blueberries, and cranberries. For each type the information includes a brief history of the particular culture, a list and description of varieties in the United States and Canada, methods of propagation, harvesting and handling, and other cultural instructions. The revision brings the book up-to-date on the newest varieties, the latest disease control methods, and irrigation practices and freezing methods. The book is copiously illustrated, although a few of the half-tone engravings are not of the best quality.

TWO EARS OF CORN—TWO BLADES OF GRASS

By D. H. Killeffer. New York, D. Van Nostrand, Inc. 139 pp. 1955. \$4.00.

Jonathan Swift was some 200 years ahead of his time when he wrote that the man who can make two ears of corn and two blades of grass grow where only one had grown before would do greater service to his country than all the world of politicians put together. This book relates in an entertaining fashion how modern scientists, notably chemists, have taken Swift at his word, quantitatively at least, to produce food and fibre in an abundance inconceivable 2½ centuries ago. The author's optimism, with respect to future world supplies, seems limitless; it is based on the phenomenal accomplishments of chemistry already in synthesizing vitamins and antibiotics, and in the fields of food production and technology; and he declares that the creative intelligence which envisioned and accomplished these feats is an inexhaustible

resource. The book is a plea for education and training to develop this resource, wherever it manifests itself, to enable science to work new "wonders" which will make today's feats seem trifling. Hydroponics and the synthesis of fats, sugars, etc., are only two fields which, the author predicts, might do away with agricultural production at it is now known. Hydroponics is at a stage today comparable to that of the airplane when the Wright brothers flew their first model, he states. While this is indeed a radical view at the moment, it cannot be disregarded. The abundance which the author foresees could eliminate the need to cry for more *lebensraum*; and the optimistic result would be a world of peace. That the world of politicians might not be able to guarantee peace even with abundance is no cause to discredit Mr. Killeffer's optimism, especially in the face of chemistry's record to date which is the basis for his confidence in the future.

NEW PRACTICAL FORMULARY

By Mitchell Freeman. Brooklyn, N. Y. The Chemical Publishing Co. 377 pp. 1955. \$7.95.

This book contains more than 2,500 formulas for a great variety of products marketed under numerous trade-marks. Included are alloys, bleaching preparations, Bordeaux mixture, fumigants, larvicides, cements, glues, cleaning preparations, soaps, laundry specialties, cosmetics and perfumes, candy and food products, inks, paints, stain removers, wall cleaners, and others. The author states that most of the formulas are in use today in the manufacture of the products, and some are newly disclosed in this volume. Of the most practical value to the manufacturer or technical worker, this book would also be helpful to vocational teachers and students. The layman himself would find it extremely interesting and revealing. An introductory chapter describes basic operations of a chemical plant. A helpful appendix lists weights and measures, conversion tables, specific gravity comparisons, and sources of supply.

Agronomic Affairs

MEETINGS

- June 15-17, Annual convention, American Seed Trade Assn., Minneapolis, Minn.
- June 25-27, American Society of Commercial Seed Technologists, Stillwater, Okla.
- June 27-29, North Central Branch, A.S.A., Iowa State College, Ames.
- June 27-30, Association of Official Seed Analysts, Stillwater, Okla.
- June 28-30, Pacific Northwest Regional Fertilizer Conference, Boise, Idaho.
- July 27-29, Northeast Branch, American Society of Agronomy, Pennsylvania State University.
- Aug. 1-6, 3rd International Congress of Biochemistry, Brussels, Belgium.
- Aug. 15-19, American Society of Agronomy and Soil Science Society of America, University of California College of Agriculture, Davis.
- Aug. 29-Sept. 6, International Horticultural Congress, Scheveningen, Holland.

AGRONOMIC MANPOWER REPORT

From time to time, members of the Agronomic Manpower Resources Committee receive inquiries relative to the use of scientists in the military, especially as related to Selective Service. People want to know what procedure a young scientist might

take, when he is drafted into the military, so that he might be assigned to a scientific activity.

The Army has a scientific and professional personnel program into which it tries to fit engineers and scientists. During the past year, Selective Service has so overloaded the Army with professional personnel that only a fraction of these men are being utilized in any activity remotely related to their specialties. Army officials have been forced to raise the qualifications for assignments in the scientific programs. Most scientists now must have a Master's degree plus a year of experience before they can qualify. Those with Ph.D's are satisfactorily placed. For those interested, direct inquiry can be made to the Chief of Classification and Standards, Branch GI, Department of the Army, Washington 25, D. C.

The Navy and the Air Force do not have comparable set-ups. The Air Force uses a great many men in specialized assignments, but without benefit of such formal arrangements as exists in the Army. The Navy apparently doesn't recognize any kind of specialization except that acquired in uniform.

A STATEMENT OF POLICY

The following Policy Statement looking toward the forging of a realistic manpower program for our country has been endorsed by the Engineering Manpower Commission of Engineers Joint Council, the Scientific Manpower Commission, the Board of Directors of the American Chemical Society and the Technical Manpower Commission of the Armed Forces Chemical Association.



SITE OF THE SOCIETY'S 1955 ANNUAL MEETING—Students chat on a bench of a covered terrace of the Soils and Irrigation Building on the University of California campus at Davis. A covered passageway connects the building with Hunt Hall, which houses the Agronomy Department and the Departments of Vegetable Crops and of Plant Pathology.

The American Society of Agronomy is represented on the SMC through the recently formed Policy Committee for Scientific Agricultural Societies (Agron. Jour. 46:595-596, 1954).

A STATEMENT OF POLICY RELATING TO SPECIALIZED PERSONNEL

When Congress passed legislation to provide for the military strength of our country it declared that "in a free society the obligations and privileges of serving in the armed forces and the reserve components thereof should be shared generally, in accordance with a system of selection which is fair and just and which is consistent with the maintenance of an effective national economy" (Section 1, c of Public Law 51, 82nd Congress).

The obligation and privilege of serving one's country in time of need has appealed to the patriotism of millions, yes billions of people, in literally hundreds of different countries. The United States has no monopoly on this feature. It is in the desire to assure a "fair and just" system of selection that the United States differs sharply from many other nations, and it is particularly important, in the interests of freedom and democracy, that every effort to provide such a system be made. Congress realized this when in the same law (Section 1, e) it declared that "adequate provision for national security requires maximum effort in the fields of scientific research and development, and the fullest possible utilization of the nation's technological, scientific, and other critical manpower resources."

These statements were incorporated into Public Law 51 on June 19, 1951, when the United States was playing a leading role in the Korean action. Since then there has been a gradual change in the world situation and in the part played by the United States. The so-called "cold war" which followed has developed into what more accurately may be called a "technological war." Recent authentic information from Russia indicates that her leaders fear our technological superiority more than anything else. In view of the Russians' greater numerical strength, technological superiority offers the best hope of assuring our national security. It is logical that the degree to which national security can be assured is in direct proportion to our margin of superiority.

While the Soviet Union is conscious of the role of technology as the basis for both military and economic power, it is also conscious of its accomplishments in this area, accomplishments that have eliminated our superiority in certain fields and left the margin uncomfortably narrow in others.

This being true, it is even more certain now than in 1951 "that adequate provisions for national security requires maximum effort in the fields of scientific research and development, and the fullest possible utilization of the nation's technological, scientific, and other critical manpower resources."

THEREFORE: In the interest of immediate as well as long range needs of our nation, it is the opinion of the Engineering Manpower Commission of Engineers Joint Council, the Scientific Manpower Commission, the Board of Directors of the American Chemical Society and the Technical Manpower Commission of the Armed Forces Chemical Association that every step should be taken:

1. To assure maximum and uninterrupted growth of scientific and technological developments by promoting a strong educational system at all levels which will produce an adequate flow of specialized personnel of outstanding qualifications.

2. To assure optimum utilization of specialized personnel through a system whereby both military and civilian needs will be fulfilled. This objective will require expert civilian and military judgment to determine where each person can contribute most to the national interest.

These broad objectives are not being met today. Because they are not being met, it is the opinion of the Engineering Manpower Commission of Engineers Joint Council, The Scientific Manpower Commission, the Board of Directors of the American Chemical Society and the Technical Manpower Commission of the Armed Forces Chemical Association that those in Government having responsibility for the administration of the manpower program should seek:

1. Modification of Public Law 51 (Universal Military training and Service Act) and its administration, including a change in title, in order to guarantee the selectivity features of the law.

2. Legislation to establish a National Manpower Board in the Office of the President composed of both civilian and military personnel whose duty it shall be to determine policy and implement the administration of matters relating to specialized personnel. This legislation shall also provide for proper organization at state and local levels to ensure adequate recognition of individual abilities and local situations which provide realistic proper utilization of each reservist.

3. Legislation to provide an immediately callable reserve, under the control of the military, of such a size that it can be well organized, highly trained, and quickly mobilized to provide an effective striking force in the event of aggression, and also

4. Legislation to provide a selectively callable reserve, whose members shall not be recalled to the military except on a selection basis under the direction of the National Manpower Board.

AGRONOMIC MANPOWER RESOURCES COMMITTEE

W. A. ALBRECHT	J. B. PETERSON
K. H. KLAGES	L. N. SKOLD
W. H. LEONARD	S. A. TAYLOR
C. L. W. SWANSON, <i>chairman</i>	

HAWAII CHAPTER LISTS ACTIVITIES

The Hawaii Chapter of the American Society of Agronomy has had a busy year, reports R. P. HUMBERT, past president of the chapter. Five meetings were held with attendance ranging from 30 to 78 people. Several interesting programs held during the past year are:

Feb. 4, 1954—"Response to Molybdenum on Legumes in Hawaii" by Dr. O. YOUNGE, and a movie, "Radio Isotopes in Agriculture" by the Atomic Energy Commission; July 30—Dean R. I. THROCKMORTON on "Midwestern Agriculture"; Nov. 9—STERLING HENDRICKS on "Ion Uptake and Utilization by Plants"; Feb. 7, 1955—RICHARD BRADFIELD on "What Factors Limit Yields of Heavily Fertilized Crops"; and March 7—STERLING WORTMAN on "Rockefeller Research in Mexico—Its Implications for Hawaii", and G. DONALD SHERMAN on "Observations on the Soils of Central and South America".

Officers elected for the present year are as follows: KARL F. MANKE, president; ZERA FOSTER, vice president; OTTO YOUNGE, secretary-treasurer; and ERNEST THOMAS, delegate at large.

J. KEITH THORNTON DIES IN PENNSYLVANIA

JOSEPH KEITH THORNTON of Lemont, superintendent of the department of farm operations and service at Pennsylvania State University since 1948, died at his home March 11.

Born May 7, 1905 in McKeesport, he was the son of Charles and Marietta Beman Thornton. He was married to Frances Martin who survives with his mother of Springboro, Pa., and four children, Joseph Keith Jr., Johnstown, and John, Charles, and Mary Faith, all at home.

A brother, one sister, and a grandchild also survive.

Mr. Thornton came to Pennsylvania State University in 1935 as instructor in farm crops after serving for eight years as assistant plant pathologist in the U.S.D.A. Bureau of Plant Industry and the Pennsylvania Department of Agriculture. He was promoted to assistant professor at Penn State in 1941, to associate professor of farm crops in 1944, and to his present post in 1948.

Mr. Thornton, who conducted extensive research on grasses, was graduated from Penn State in 1927 and received his master's degree from the University of Wisconsin in 1947.

He was a member of the Spring Creek Presbyterian Church of Lemont, the Western Crawford Lodge F and AM of Conneautville and the Lemont Lions. He was a member of the College Township School Board for more than seven years and of the College Area School Board until he retired early this year because of illness.

J. L. SCHWENDIMAN RECEIVES AWARD

Plant Material Specialist JOHN L. SCHWENDIMAN received the Junior Chamber of Commerce-Sears Foundation 1954 Achievement in Agriculture award for the state of Washington for his contributions in developing new grasses and legumes for conservation use in the Northwest. For the past 10 years he has been agronomist and manager of the U.S.D.A. S.C.S. nursery at Pullman, Wash., where, in cooperation with State Experiment Stations, 18 improved strains were released. These include Whitmar beardless wheatgrass, Manchar smooth brome, Sherman big bluegrass, Volga wildrye, hard fescue, Topar pubescent wheatgrass, and other new grasses which are now being widely used in conservation seedings.

INDIAN INSTITUTE OBSERVES JUBILEE

The Indian Agricultural Research Institute, New Delhi, popularly known as the Pusa Institute, celebrated its Golden Jubilee April 1-4. The Institute was established in 1905 at Pusa, Bihar, with the help of a donation from the American philanthropist, Henry Phipps. It was located at Pusa until the earthquake of 1934 caused irreparable damage to the laboratory buildings. It was then moved to New Delhi. New laboratories and buildings were opened in November, 1936.

There are at present six major divisions within the Institute: Agronomy, Botany, Soil Science and Agricultural Chemistry, Agricultural Engineering, Entomology and Mycology and Plant Pathology. Recently, the Institute undertook agricultural extension work in Delhi villages. Besides these activities, it co-operates with the Food and Agriculture Organization of U.N. in the maintenance and description of genetic stocks of wheat and with the Technical Co-operation Mission of the United States in conducting trials of certain fertilizers in different parts of India.

OREGON STATION INVITES ANNUAL MEETING ATTENDANTS TO INSPECT RESEARCH AT CORVALLIS

Members of the American Society of Agronomy are invited to view research being conducted at the Oregon Agricultural Experiment Station in Corvallis, Oreg., either before or after the Society's annual meeting at Davis, California, Aug. 15-19.

D. D. HILL, Head of Farm Crops, and H. B. CHENEY, Head of Soils, at Oregon State College report morning and afternoon tours will be conducted daily. Details will be contained in a brochure which will be mailed soon to agronomy and soils departments at other institutions.

COMMITTEES FOR 1955 AMERICAN SOCIETY OF AGRONOMY

(A partial list of Society committees for 1955 was published in the February 1955 issue, page 109, of *Agronomy Journal*)

EDITORIAL BOARD—*What's New in Crops & Soils*

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REGIONAL BRANCH COORDINATION

S. R. ALDRICH, <i>Northeast</i>	ERIC WINTERS, <i>Southern</i>
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AWARDS

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NEWS ITEMS

GARTH K. VOIGT left the University of Wisconsin Jan. 4 to take charge of instruction and research in forest soils in a new forest biology program at the Yale School of Forestry, New Haven, Conn. The program is supported by the John A. Hartford Foundation, Inc. Much of the research work will be conducted on a 300-acre tract near Valhalla, N. Y., which the Foundation has leased to Yale University. Prof. Voigt succeeds H. J. LUTZ who has been named director of research under the new program.

MARVIN D. WHITEHEAD has been appointed assistant professor of field crops at the University of Missouri. He began work in Missouri on March 1. Whitehead received his B.S. and M.S. degrees at Oklahoma A. & M. College and his Ph.D. in plant pathology from the University of Wisconsin. He comes to Missouri from Texas A. & M. College where he has been plant pathologist since 1949.

B. H. BEARD, Research Agronomist, U.S.D.A., is now located at University of Minnesota's Department of Agronomy and Plant Genetics where he will work on barley breeding and testing.

R. T. RAMAGE, former teaching assistant in the University of Minnesota Department of Agronomy and Plant Genetics, is now research agronomist, U.S.D.A., at Davis, Calif. His main project will be breeding and genetics of barley.

ORVIN E. RUD, former research assistant in the University of Minnesota's Department of Agronomy and Plant Genetics, is now research instructor at North Carolina State College. He will work on weed control in soybeans, peanuts, and other crops.

ROY L. DONAHUS is on leave from the University of New Hampshire, conducting a fertilizer survey in Greece. He expects to return to the United States in June.

RAY HAMMONS, Purdue forage grass breeder, left March 1 to take a position with the U.S.D.A. in Tifton, Ga. Hammons will be in charge of the peanut breeding improvement program for the Southeastern states. During the 20 months Dr. Hammons was at Purdue, he specialized in the breeding of better strains of brome grass and orchard grass.

ROBERT T. RAMAGE, who recently received his Ph.D. degree in plant genetics at the University of Minnesota, is now located at Davis, Calif., as Associate in the California Experiment Station, and Agronomist with the USDA Cereal Crops Section. He will conduct work on fundamental barley genetics.

KENNETH L. VISTE has been appointed as Associate in the California Experiment Station, and Cooperative Agent with the USDA Weed Investigation Section at Davis, Calif., working on rice weed research. He recently received the M.S. degree in Agronomy from the University of California.

BOYCE C. WILLIAMS was recently appointed Assistant in Agronomy at the New Mexico Experiment Station. He received his Ph.D. degree in soil science at Michigan State College in March. He will do research on sodium soils.

PAUL A. FRYXELL has returned to the New Mexico Experiment Station after a 3-month leave during which he completed the Ph.D. requirements in genetics at Iowa State College. He is now engaged in cotton breeding and genetics.

HARRY T. BRYANT, who graduated from the University of Maine and also received a M.S. degree from that institution and the Ph.D. degree from the University of Wisconsin, has accepted a position as associate agronomist with the Virginia Experiment Station. He is officer-in-charge of the Northern Virginian Pasture Research Station at Middleburg.

COLEMAN Y. WARD, a graduate of Texas Tech where he also received the M.S. degree, has accepted a position as assistant agronomist in forage crops research with Virginia Experiment Station at Blacksburg.

PERSONNEL SERVICE

The Personnel Service column is provided without charge to American Society of Agronomy and Soil Science Society of America members. For all others, a charge of \$2.00 is made. Insertions are limited to 100 words, and should be submitted in duplicate. An item will be inserted one time only, but will be given a key number which will be carried for five additional insertions unless a discontinue order is received. Items pertaining to soils positions will be inserted one time in the *Soil Science Society of America Proceedings* unless otherwise specified. The following insertions, published in earlier issues, are still available: 11-1, 11-2, 12-1, 1-1, 2-1, 2-2, 2-3.

POSITIONS WANTED

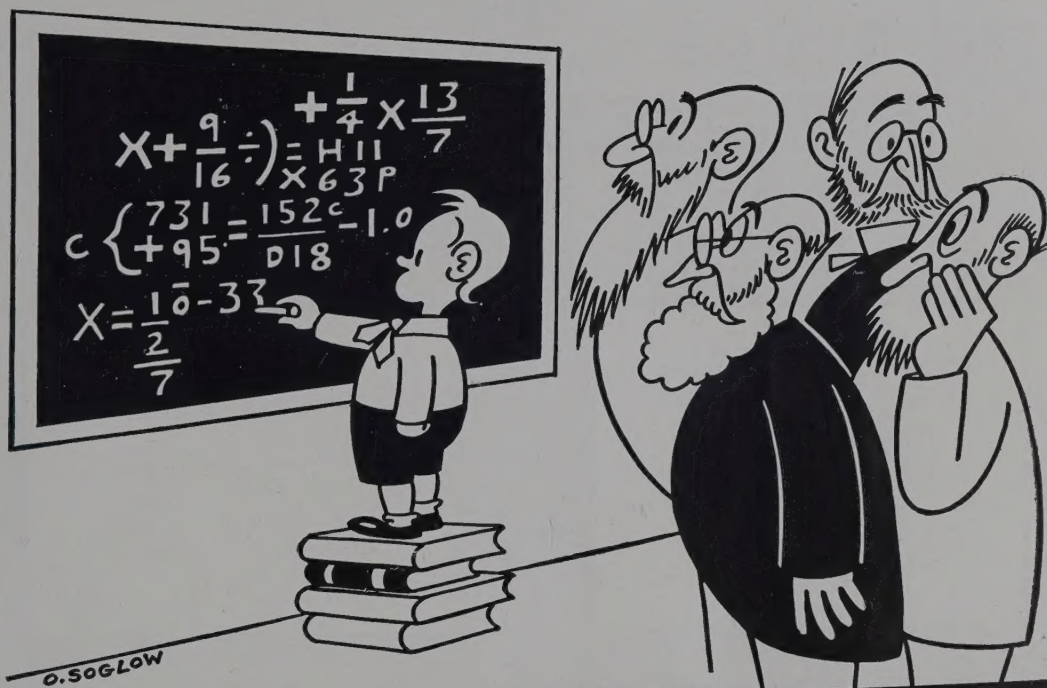
Agronomist (Ph.D., Soil Fertility) experienced in teaching (Crops and Soils), research, extension, and conservation, desires position in line with experience and training. Available June 1 or Aug. 15.

Agronomist, Ph.D. candidate (will receive degree in June 1955) majoring in Soil Conservation, minoring in Crop Ecology and Land Economics, with teaching and research experience, desires research or teaching position.

Agronomist, B.S. in agronomy, University of Kentucky, employed for past 2 years with engineering firm in industrial research and development in Soil Conditioning; good foundation in Soil Physics and Chemistry, Microbiology, and Analytical Chemistry. Prior work for 2½ years with Agronomy Department, Univ. of Kentucky Agricultural Experiment Station, in research on portable irrigation systems for pasture and tobacco land fertilization. Veteran, 29 years old, married, no children. Seeks position in line with above qualifications.

FOR SALE

Set of *Agronomy Journal*, vols. 20 through 40, good condition. Also *Soil Science*, Boyce Thompson, other soil journals. Edwin Harrington, Agricultural Chemist, Carversville, Pa.



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For correction of Chlorosis resulting from iron deficiencies by spray or dust application to the plant.

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